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# PUBLIC ROADS ▸ ▸ ▸ *A Journal of Highway Research*

*Issued by the*

FEDERAL WORKS AGENCY

PUBLIC ROADS ADMINISTRATION

D. M. BEACH, *Editor*

Volume 22, No. 3 May 1941

*The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.*

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# PROGRESS IN EXPERIMENTS WITH CONTINUOUS REINFORCEMENT IN CONCRETE PAVEMENTS[1]

Reported by HARRY D. CASHELL, Assistant Highway Engineer, Public Roads Administration, and SANFORD W. BENHAM, Research Engineer, Indiana Highway Commission

This report contains data obtained during the first 2 years of observation of continuously reinforced concrete pavement sections.

Changes in pavement elevation have been small and there is nothing to indicate that these changes have affected the structural condition of the various sections.

The annual cycle of length change of the various sections shows that those approximately 150 feet long move with as much freedom as the very short sections. The movement of sections greater than 150 feet long is apparently restrained by the subgrade and this restraint is progressively greater as the section length is increased.

In the long, heavily reinforced sections many fine cracks have developed in the central areas. In the sections of intermediate length containing ½-inch steel bars a moderate amount of cracking has developed, while only a very limited amount of cracking has occurred in the short sections containing welded wire fabric. Although the width of the cracks is slightly greater in the sections containing the smaller amounts of longitudinal steel there is no evidence of spalling, raveling, disintegration, steel failure, or other structural weakness at any of the cracks. A relation between the length of the section as constructed and the average slab length (or the distance between transverse cracks) appears to exist. So far, no relation has been found between the average slab length and either the type or the amount of longitudinal steel.

Relative roughness determinations over the various sections show that the surface of the sections was very smooth after about 18 months of service.

THIS is the second report describing an experimental reinforced concrete pavement investigation that is being conducted by the Public Roads Administration and the Indiana State Highway Commission. In the first report[2] the scope of the study was outlined in detail and the construction of the experimental pavement was described. The present report contains a general discussion of the current condition of the pavement, with data showing the more important developments and trends that have become evident during its 2-year life. The purpose of this report is not to draw definite conclusions regarding the relative merits of the various sections, but to present data that will show the observed behavior to date.

To enable a better understanding of the data, certain essential details of design that were presented in the first report will be repeated here. The number and length of the sections and the amount and type of reinforcement used in each are given in tables 1, 2, and 3.[3] It will be noted that the values of the calculated maximum steel stresses are such as to permit direct comparison between sections containing different types as well as different percentages of longitudinal steel. The average unit tensile strength of each of the different types and sizes of steel reinforcement as found by tests is given in table 4. It is apparent from these data that the yield points of both the billet and rail steel bars are appreciably higher than the calculated maximum stresses shown in tables 2 and 3.

In addition to the regular sections, four other sections were included in which special joint designs and different methods of reinforcing were employed. The essential common features of these four sections are: (1) Each section is 500 feet long; (2) weakened-plane joints were placed at 10-foot intervals in each; (3) reinforcement consisted of welded fabric placed continuously through the weakened-plane joint; (4) the bond between the steel and the concrete was broken for a distance of 18 inches on each side of each weakened-plane joint by omitting the transverse steel at this point and by greasing; and (5) dowel bars for load transfer were placed across one-half of the weakened-plane joints of each section.

The distinguishing features of the four sections are as follows:

No. 1. Weakened-plane joints are of the submerged type and the welded fabric reinforcement weighs 91 pounds per square.

No. 2. This section is the same as No. 1, except that it is reinforced with a 45-pound welded fabric.

No. 3. Weakened-plane joints are of the surface groove type and the reinforcement weighs 91 pounds per square.

No. 4. The section is the same as No. 3, except that it is reinforced with a 45-pound welded fabric.

The amount of longitudinal steel in the 91-pound welded fabric is 77 pounds per square; that in the 45-pound welded fabric is 35 pounds per square.

The strength of the concrete was determined by compression tests on drilled cores at the age of 6 months. The average strength was found to be 6,360 pounds per square inch. The average density of the concrete was 154 pounds per cubic foot.

The experimental pavement was constructed during September and October 1938 as a regular Federal-aid project, being a part of the transcontinental highway U S 40. Approximately 1½ miles of this 6-mile experimental pavement has been subject to heavy truck and passenger-car traffic for nearly 2 years, while the remaining 4½ miles has been under the same traffic for 1½ years.

The schedule of observations described in the first report has been adhered to, and for detailed information concerning this program the reader is referred to the first report. Briefly, the schedule comprises:

1. Measurement of changes in pavement elevation.
2. Measurement of changes in length of the experimental sections.
3. Condition and crack surveys.

[1] Paper presented at the Twentieth Annual Meeting of the Highway Research Board, December 1940.

[2] Experiments with Continuous Reinforcement in Concrete Pavements, by Earl C. Sutherland and Sanford W. Benham. Proceedings of the Highway Research Board, vol. 19, 1939; also PUBLIC ROADS, vol. 20, No. 11, January 1940.

[3] The lengths of sections given in these tables are nominal lengths and may be either 5 feet or 10 feet greater than the actual length as laid in cases where the type I or type II expansion joints were installed.

TABLE 1.—*Details of steel reinforcement in experimental reinforced concrete pavement;* [1] *cold drawn wire (welded fabric)*

| Number of sections | Length of each section | Calculated maximum stress in steel | Reinforcement size and spacing | | Weight of longitudinal steel |
|---|---|---|---|---|---|
| | | | Longitudinal | Transverse | |
| | *Feet* | *Pounds per square inch* | | | *Pounds per 100 square feet* |
| **149-POUND** | | | | | |
| 6 | 140 | 25,000 | No. 4-0; d=0.3938 inch; 4 inches center to center. | No. 3; 12 inches center to center. | 132 |
| 6 | 190 | 35,000 | | | |
| 6 | 250 | 45,000 | | | |
| 6 | 310 | 55,000 | | | |
| **107-POUND** | | | | | |
| 6 | 90 | 25,000 | No. 4-0; d=0.3938 inch; 6 inches center to center. | No. 3; 12 inches center to center. | 91 |
| 6 | 130 | 35,000 | | | |
| 6 | 170 | 45,000 | | | |
| 6 | 200 | 55,000 | | | |
| **91-POUND** | | | | | |
| 6 | 80 | 25,000 | No. 3-0; d=0.3625 inch; 6 inches center to center. | No. 4; 12 inches center to center. | 77 |
| 6 | 110 | 35,000 | | | |
| 6 | 140 | 45,000 | | | |
| 6 | 170 | 55,000 | | | |
| **65-POUND** | | | | | |
| 6 | 60 | 25,000 | No. 0; d=0.3065 inch; 6 inches center to center. | No. 6; 12 inches center to center. | 55 |
| 6 | 80 | 35,000 | | | |
| 6 | 100 | 45,000 | | | |
| 6 | 120 | 55,000 | | | |
| **45-POUND** | | | | | |
| 6 | 30 | 25,000 | No. 3; d=0.2437 inch; 6 inches center to center. | No. 6; 12 inches center to center. | 35 |
| 6 | 50 | 35,000 | | | |
| 6 | 60 | 45,000 | | | |
| 6 | 80 | 55,000 | | | |
| **32-POUND** | | | | | |
| 6 | 20 | 25,000 | No. 6; d=0.1920 inch; 6 inches center to center. | No. 6; 12 inches center to center. | 22 |
| 6 | 30 | 35,000 | | | |
| 6 | 40 | 45,000 | | | |
| 6 | 50 | 55,000 | | | |

[1] Sections are 10 feet wide.

In addition to these observations, during the past year measurements were made of the relative surface roughness of the various sections. The results of all of these various studies are presented in this report.

#### PAVEMENT ELEVATIONS DETERMINED PERIODICALLY

In connection with the presentation of the pavement elevation data certain pertinent physical characteristics and moisture determinations of the subgrade are given in table 5. The soil samples were taken from the finished subgrade at the depths indicated.

The first set of elevation measurements to establish the normal elevation of the pavement was started as soon as possible after the necessary bench marks had been established and the measuring points installed in the pavement.

Unfortunately, the first set of elevation measurements had been completed on only about 1½ miles of the experimental pavement before the first freezing weather occurred, so it cannot be certain that the remaining portion was entirely undisturbed at the time of the first measurements. However, the winter of 1938–39 was generally mild in this area and frost did not penetrate more than a few inches at any time.

TABLE 2.—*Details of steel reinforcement in experimental reinforced concrete pavement;* [1] *billet steel bars (intermediate grade—deformed)*

| Number of sections | Length of each section | Calculated maximum stress in steel | Reinforcement size and spacing | | Weight of longitudinal steel |
|---|---|---|---|---|---|
| | | | Longitudinal | Transverse | |
| | *Feet* | *Pounds per square inch* | | | *Pounds per 100 square feet* |
| 2 | 360 | 15,000 | 1-inch round bars; 6 inches center to center. | ½-inch round bars; 24 inches center to center. | 534 |
| 2 | 600 | 25,000 | | | |
| 2 | 840 | 35,000 | | | |
| 2 | 1,080 | 45,000 | | | |
| 4 | 200 | 15,000 | ¾-inch round bars; 6 inches center to center. | ½-inch round bars; 24 inches center to center. | 300 |
| 4 | 340 | 25,000 | | | |
| 4 | 470 | 35,000 | | | |
| 4 | 610 | 45,000 | | | |
| 4 | 90 | 15,000 | ½-inch round bars; 6 inches center to center. | ½-inch round bars; 24 inches center to center. | 134 |
| 4 | 150 | 25,000 | | | |
| 4 | 210 | 35,000 | | | |
| 4 | 270 | 45,000 | | | |
| 6 | 50 | 15,000 | ⅜-inch round bars; 6 inches center to center. | ⅜-inch round bars; 24 inches center to center. | 75 |
| 6 | 80 | 25,000 | | | |
| 6 | 120 | 35,000 | | | |
| 6 | 150 | 45,000 | | | |
| 6 | 20 | 15,000 | ¼-inch round bars; 6 inches center to center. | ¼-inch round bars; 12 inches center to center. | 33 |
| 6 | 40 | 25,000 | | | |
| 6 | 50 | 35,000 | | | |
| 6 | 60 | 45,000 | | | |

[1] Sections are 10 feet wide.

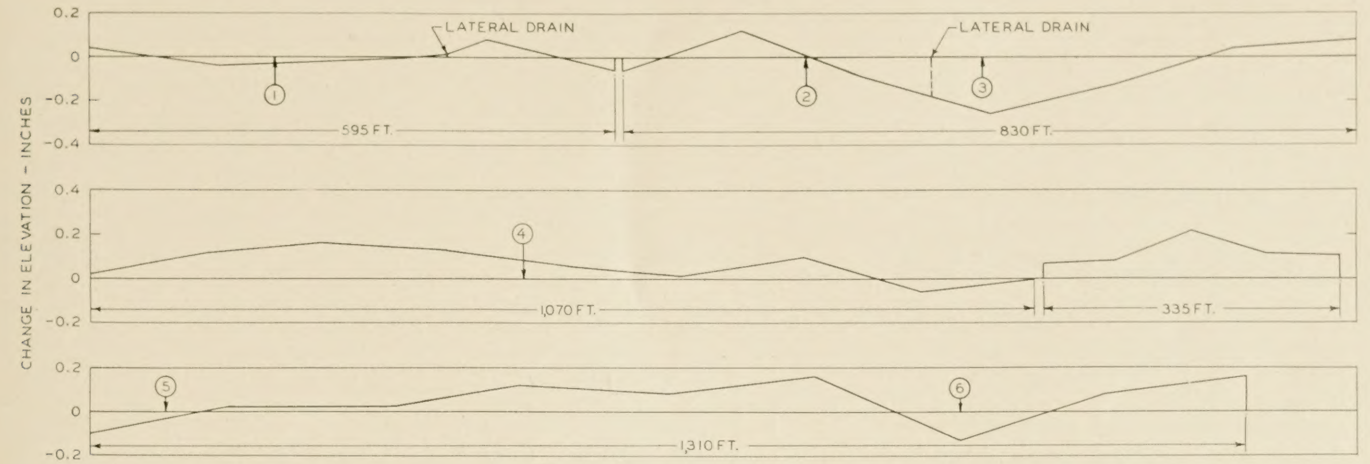
TABLE 3.—*Details of steel reinforcement in experimental reinforced concrete pavement;* [1] *rail steel bars (deformed)*

| Number of sections | Length of each section | Calculated maximum stress in steel | Reinforcement size and spacing | | Weight of longitudinal steel |
|---|---|---|---|---|---|
| | | | Longitudinal | Transverse | |
| | *Feet* | *Pounds per square inch* | | | *Pounds per 100 square feet* |
| 2 | 600 | 25,000 | 1-inch round bars; 6 inches center to center. | ½-inch round bars; 24 inches center to center. | 534 |
| 2 | 840 | 35,000 | | | |
| 2 | 1,080 | 45,000 | | | |
| 2 | 1,320 | 55,000 | | | |
| 4 | 340 | 25,000 | ¾-inch round bars; 6 inches center to center. | ½-inch round bars; 24 inches center to center. | 300 |
| 4 | 470 | 35,000 | | | |
| 4 | 610 | 45,000 | | | |
| 4 | 740 | 55,000 | | | |
| 4 | 150 | 25,000 | ½-inch round bars; 6 inches center to center. | ½-inch round bars; 24 inches center to center. | 134 |
| 4 | 210 | 35,000 | | | |
| 4 | 270 | 45,000 | | | |
| 4 | 330 | 55,000 | | | |
| 6 | 80 | 25,000 | ⅜-inch round bars; 6 inches center to center. | ⅜-inch round bars; 24 inches center to center. | 75 |
| 6 | 120 | 35,000 | | | |
| 6 | 150 | 45,000 | | | |
| 6 | 180 | 55,000 | | | |
| 6 | 40 | 25,000 | ¼-inch round bars; 6 inches center to center. | ¼-inch round bars; 12 inches center to center. | 33 |
| 6 | 50 | 35,000 | | | |
| 6 | 60 | 45,000 | | | |
| 6 | 80 | 55,000 | | | |

[1] Sections are 10 feet wide.

The second set of elevation measurements over the full length of the experimental sections was made during October 1939, the pavement then being about 1 year old. It is believed that by this time the subgrade had attained a normal moisture condition throughout and the pavement slab was at an elevation normal for the season.

The third set of elevation measurements over the full length of the experimental sections was made in January 1940. This was a severe winter and frost had penetrated to a depth of about 20 inches at the time of the measurements.




| SOIL SAMPLE NO. | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| | PERCENT | | | | | |
| SILT | 58 | 63 | 39 | 54 | 46 | 43 |
| CLAY | 18 | 13 | 12 | 23 | 19 | 18 |
| LIQUID LIMIT | 37 | 43 | 28 | 39 | 35 | 29 |
| PLASTICITY INDEX | 12 | 19 | 11 | 16 | 14 | 11 |

| SOIL SAMPLE NO. | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| | PERCENT | | | | | |
| MOISTURE CONTENT: 0-3 INCH DEPTH | 11.5 | 12.9 | 19.2 | 17.0 | 16.8 | 9.8 |
| 3-12 INCH DEPTH | 14.6 | 15.8 | 13.5 | 21.4 | 18.7 | 15.7 |
| 12-24 INCH DEPTH | 13.1 | 20.9 | 13.5 | 21.2 | 19.6 | 12.8 |

FIGURE 1.—CHANGES IN ELEVATION OF CERTAIN SECTIONS OF PAVEMENT AT END OF FIRST YEAR, AND PHYSICAL CHARACTERISTICS OF SUBGRADE SOIL.

TABLE 4.—*Tensile strength of steel reinforcement*

WELDED FABRIC

| Weight | Average tensile strength | |
|---|---|---|
| | Longitudinal wires | Transverse wires |
| *Lb. per sq.* | *Lb. per sq. in.* | *Lb. per sq. in.* |
| 32 | 88,700 | 84,767 |
| 45 | 81,000 | 87,000 |
| 65 | 83,700 | 87,800 |
| 91 | 89,100 | 88,867 |
| 107 | 80,250 | 86,150 |
| 149 | 81,820 | 81,820 |

BILLET STEEL BARS

| Diameter | Average tensile strength | |
|---|---|---|
| | Yield point | Ultimate |
| *Inch* | *Lb. per sq. in.* | *Lb. per sq. in.* |
| ¼ | 56,850 | 77,300 |
| ⅜ | 55,480 | 81,940 |
| ½ | 51,433 | 78,567 |
| ¾ | 49,132 | 78,468 |
| 1 | 46,943 | 78,033 |

RAIL STEEL BARS

| | | |
|---|---|---|
| ¼ | 60,250 | 84,600 |
| ⅜ | 66,650 | 93,625 |
| ½ | 68,768 | 115,312 |
| ¾ | 64,428 | 113,255 |
| 1 | 63,342 | 113,202 |

Other measurements of the elevation of certain selected sections of the pavement have been made from time to time.

In figure 1 are shown the changes in pavement elevation that had occurred on typical sections at the end of the first year of pavement life, using the elevations determined in the fall of 1938 as a base. The moisture condition and other subgrade soil data at the time the pavement was placed are shown also in this figure. Although no moisture determinations were made at the time the second set of elevation data was obtained, it is only reasonable to expect that changes had occurred

TABLE 5.—*Subgrade soil data*

| | Silt | Clay | Liquid limit | Plasticity index | Moisture content | | |
|---|---|---|---|---|---|---|---|
| | | | | | 0-3 inches below surface | 3-12 inches below surface | 12-24 inches below surface |
| | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| Maximum | 65 | [1] 26 | 52 | 26 | 22.6 | 24.0 | 27.5 |
| Minimum | 20 | 7 | 19 | 4 | 6.1 | 8.9 | 8.1 |
| Average | 48 | 17 | 33 | 12 | 12.8 | 15.5 | 17.1 |

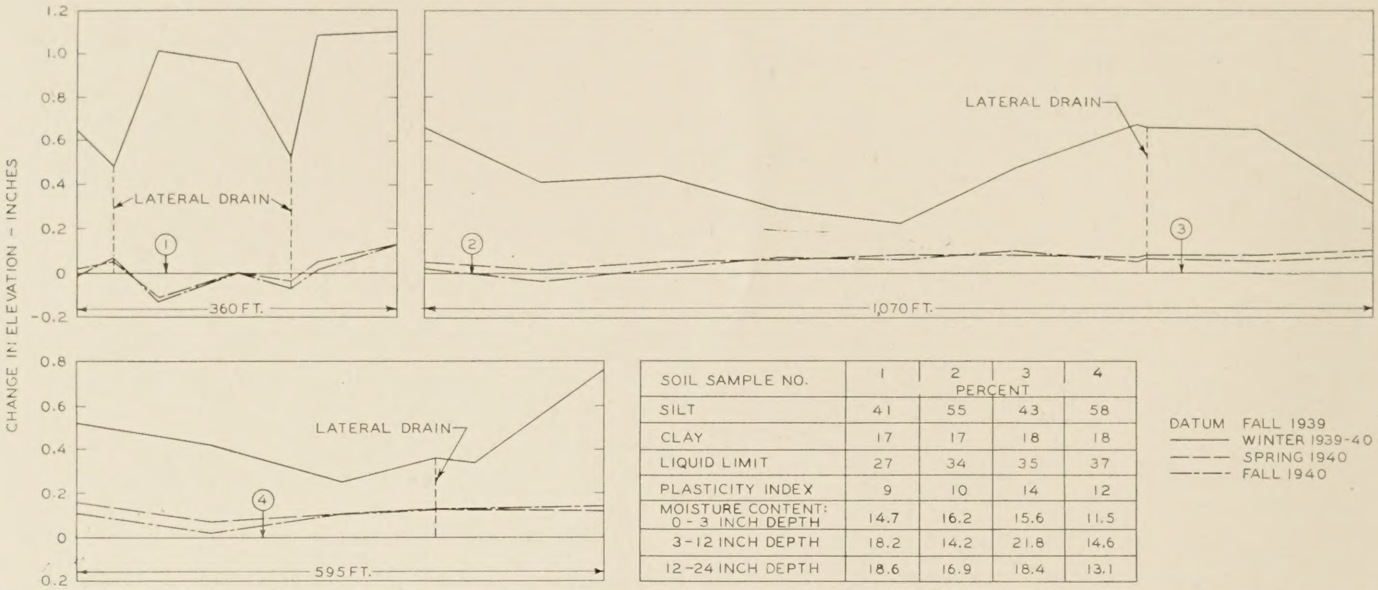
[1] This maximum percentage was exceeded in two instances; however, these cases were not considered as representative of the entire project.

during the year since the concrete was placed. It is believed that the changes in pavement elevation that had developed during this period were caused by changes in the physical state of the subgrade soil.

It will be noted that little change occurred at any point in the 595-foot section. In the 830-foot section the most noticeable change was a settlement of 0.2 inch near the center. It was observed that the subgrade in this area was somewhat spongy at the time the concrete was placed. Figure 1 shows that over much of the length of both the 335-foot and the 1,070-foot sections the elevation increased 0.1 to 0.2 inch, while on the 1,310-foot section slight increases and slight decreases developed in certain areas during the first year.

The data in figure 1 give a fair indication of the general order of the changes in elevation that were observed at the end of the first year. Over the entire length of the experimental sections no change in elevation of more than 0.5 inch was found at this time.

Using as a datum the elevations measured on the pavement surface in October 1939, when presumably the sections had stabilized at their normal position for this season of the year, the positions of certain selected sections are shown in figures 2, 3, and 4 as they were found to be: (1) In January 1940 with the subgrade frozen deeply; (2) in May 1940 after thawing was complete; and (3) in October 1940 after the annual cycle of change was again completed.




| SOIL SAMPLE NO. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| | PERCENT | | | |
| SILT | 41 | 55 | 43 | 58 |
| CLAY | 17 | 17 | 18 | 18 |
| LIQUID LIMIT | 27 | 34 | 35 | 37 |
| PLASTICITY INDEX | 9 | 10 | 14 | 12 |
| MOISTURE CONTENT: 0 - 3 INCH DEPTH | 14.7 | 16.2 | 15.6 | 11.5 |
| 3 - 12 INCH DEPTH | 18.2 | 14.2 | 21.8 | 14.6 |
| 12 - 24 INCH DEPTH | 18.6 | 16.9 | 18.4 | 13.1 |

FIGURE 2.—SEASONAL CHANGES IN ELEVATION OF SELECTED SECTIONS DURING THE SECOND YEAR, AND PHYSICAL CHARACTERISTICS OF SUBGRADE SOIL.

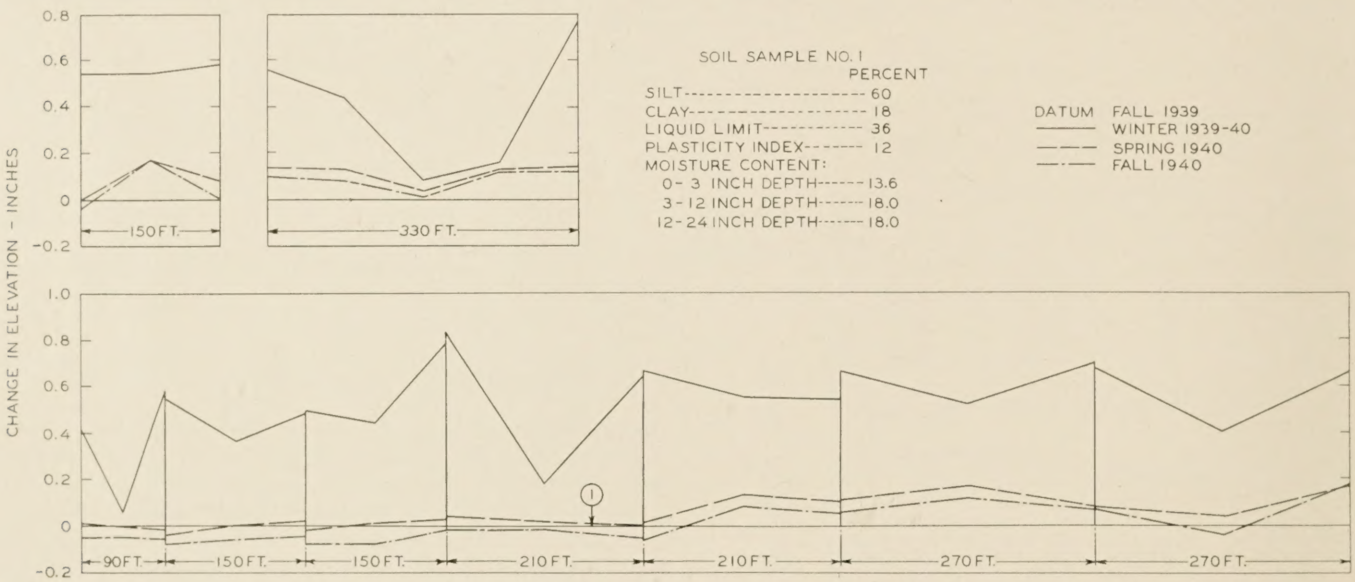



FIGURE 3.—SEASONAL CHANGES IN ELEVATION OF SELECTED SECTIONS DURING THE SECOND YEAR, AND PHYSICAL CHARACTERISTICS OF SUBGRADE SOIL.

In these figures the data are divided into three groups on the basis of the amount of longitudinal reinforcement present (and indirectly the general length of the sections). In figure 2 are shown data for sections containing 1-inch diameter bars and of considerable length; in figure 3 are data for those containing ½-inch diameter bars and of intermediate section length; while in figure 4 are data for relatively short sections reinforced with welded wire fabric.

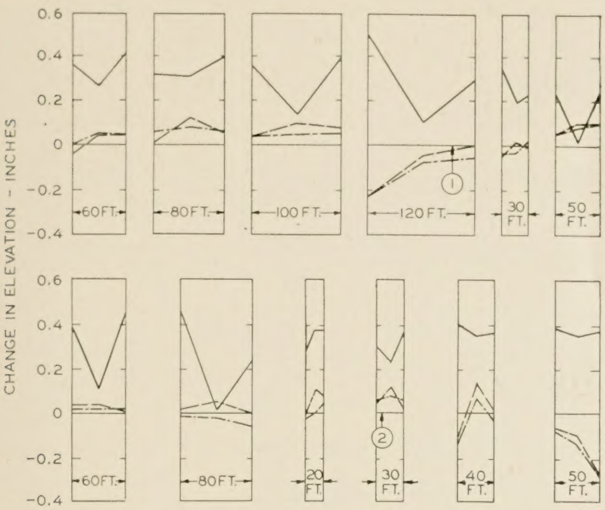
It is of interest to note that the changes in elevation caused by freezing are (1) of relatively small magnitude; (2) not uniform; and (3) frequently greater at the expansion joints than elsewhere in the sections.

Figure 5 contains similar data showing changes in elevation caused by freezing at six joints in the central area of each of the four 500-foot sections, which have warping joints at 10-foot intervals. The same general order and nonuniformity of heaving is evident in these sections. It appears, however, that the warping joints were better sealed and did not aggravate the frost heaving, in contrast to the expansion joints in the longer sections.

In spite of the deep freezing the magnitude of the frost heaving is not large, being generally within the range 0.2 to 1.0 inch. It is not uniform, varying probably with the physical characteristics and condition of the subgrade soil. In this connection it is of interest to note that at places where lateral drains were placed under the 360-foot section the magnitude of the frost heaving was less than at any other point.

It is believed that the flexure caused by the nonuniformity of the frost heaving was not sufficient to fracture the sections and the condition surveys confirm this.

After the soil had competely thawed, the elevation of the pavement was, in general, slightly greater than before freezing occurred. Between May 1940 and October 1940 little or no change in pavement elevation developed.




| SOIL SAMPLE NO. | 1 | 2 |
|---|---|---|
| | PERCENT | |
| SILT | 43 | 38 |
| CLAY | 18 | 16 |
| LIQUID LIMIT | 34 | 32 |
| PLASTICITY INDEX | 11 | 14 |
| MOISTURE CONTENT: 0 - 3 INCH DEPTH | 11.0 | 16.0 |
| 3 - 12 INCH DEPTH | 13.0 | 18.0 |
| 12 - 24 INCH DEPTH | 19.0 | 18.0 |

Figure 4.—Seasonal Changes in Elevation of Selected Sections During the Second Year, and Physical Characteristics of Subgrade Soil.

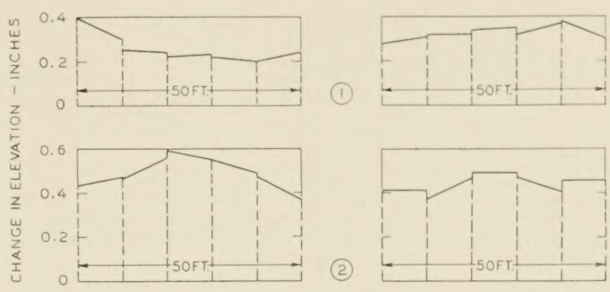
These data emphasize the importance of subgrade uniformity and of tightly sealed joints as aids in maintaining the structural integrity of concrete pavements exposed to freezing conditions.

### DAILY AND ANNUAL CHANGES IN SECTION LENGTH OBSERVED

As a part of the regular schedule, measurements are made of the daily and annual changes in section length [4] of a number of representative sections. The daily change in length is primarily that caused by the temperature change, but the annual change combines the length changes caused by temperature and moisture changes with any permanent change in length from other causes. In the present report only the annual change in length will be discussed. Measurements of this movement are made at the expansion joints of 1 section of each length for each of 3 types of reinforcement, a total of 64 sections.

In figure 6 are shown the average maximum changes in length observed for sections of different length during the first and the second years of pavement life. The changes in average pavement temperature accompanying these changes in length were 63° F. for the first year and 87° F. for the second year. For clarity in presentation, the points representing observed values for the first year are omitted from the graph. The two light straight lines, that appear to be tangent to the lower portion of the two curves, were drawn through the points for the shorter sections and thus represent the relation for short sections that are comparatively free to expand and contract.

The type of reinforcement used in the various sections is denoted by the character of symbol and it is apparent that type of reinforcement exercises no significant




| SOIL SAMPLE NO. | 1 | 2 |
|---|---|---|
| | PERCENT | |
| SILT | 47 | 43 |
| CLAY | 15 | 18 |
| LIQUID LIMIT | 44 | 33 |
| PLASTICITY INDEX | 14 | 12 |
| MOISTURE CONTENT: 0 - 3 INCH DEPTH | 21.0 | 18.0 |
| 3 - 12 INCH DEPTH | 24.0 | 18.0 |
| 12 - 24 INCH DEPTH | 19.0 | 17.0 |

Figure 5.—Increase in Elevation of Sections Containing 10-foot Slabs Caused by Freezing of Subgrade to a Depth of 20 Inches.

influence on the magnitude of the length changes thus far observed.

The two curves in figure 6 represent length changes that accompanied temperature changes of quite different magnitude. When the two sets of data are reduced to a common temperature base, it is found that the length changes observed during the second year, for sections exceeding 600 feet in length, are appreciably greater than those during the first year. For example, take the extreme case of the 1,310-foot section. During the first year the observed change in its length was 1.64 inches. Multiplying this by the temperature ratio 87/63 gives 2.27 inches, the change in length that might be expected with an 87° change in temperature. During the second year, however, a change in length of 2.72 inches was observed. Thus, it appears that the change in length was affected by temperature and also by other influences. It seems possible that the restraint offered by the subgrade may have been less after the pavement had been through an annual cycle of moisture and temperature change.

The difference in restraint increases with section length up to lengths of about 1,000 feet, after which it is practically constant, indicating that it is more probably the result of changes in soil resistance than of other causes.

When the changes in length observed during the two annual cycles are reduced to unit values per degree temperature change and related to the corresponding section lengths, the curves shown in figure 7 result. This figure is of interest in showing how the magnitude of the annual length change varies with the length of the section. The unit length change, although expressed in terms of temperature, is not actually a coefficient of thermal change alone but rather a coefficient of length change that involves temperature, moisture, and perhaps other influences. The relation is useful in indicating the order of movement to be expected at the ends of pavement slabs of various lengths. It appears from this figure that for sections up to 150 feet in length the coefficient has a value of about 0.000004. As the length of section is increased to about 600 feet, the value of the coefficient is reduced to about 75 percent of that for short sections; while for sections

[4] The term "annual change in section length," as used in this report, refers to the observed changes in length that occur between midwinter and midsummer. The values given are, therefore, approximately the maximum for the annual cycle.

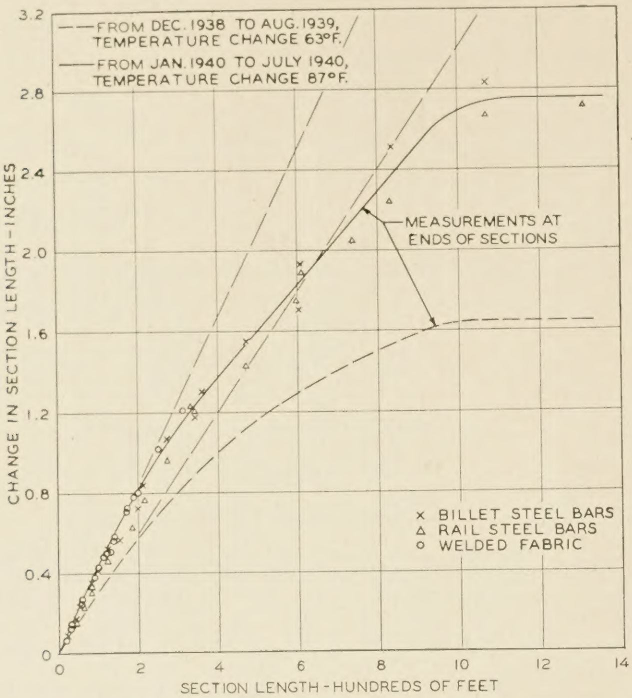



Figure 6.—Relation Between Section Length and Annual Change in Length.

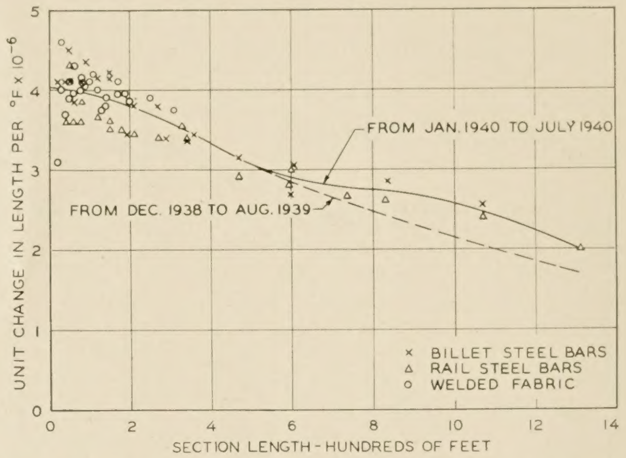



Figure 7.—Relation Between Section Length and Annual Expansion.

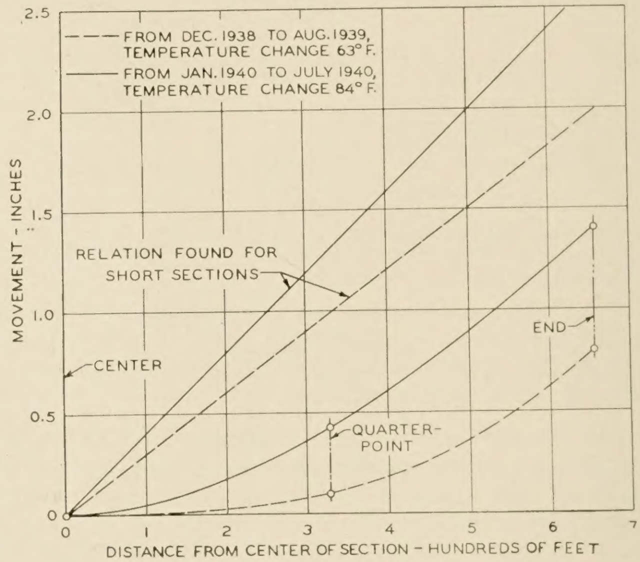



Figure 8.—Annual Movement at the Center, Quarter-point, and End of a 1,310-foot Section.

1,200 to 1,300 feet in length it is reduced to about 50 percent.

In the discussion of figure 6 it was pointed out that for long sections the changes in length that accompanied a given temperature change were greater during the second year than during the first year. This is shown perhaps more clearly in figure 7.

The annual longitudinal movements observed at the center, quarter-points, and ends of the 1,310-foot section are shown for each of the two years in figure 8. The value shown for the quarter-point and that shown for the end is in each case the average of the measurements at both quarter-points and at both ends of this section. In this graph are shown also straight-line relationships between movement and section length as observed on the short and relatively unrestrained slabs during each annual period.

During the first year the movement at the quarter-points was about 10 percent and at the ends about 40 percent of that which would be expected in a free slab of this length. During the second cycle the movement at the quarter-points was about 33 percent and at the ends about 54 percent of that of the hypothetical unrestrained section. This is added evidence that less restraint to longitudinal movement was present during the second cycle of length change.

#### NUMEROUS CRACKS FORMED IN LONG, HEAVILY REINFORCED SECTIONS

Figures 9, 10, and 11 are typical crack survey sheets, including data obtained in the six surveys made up to this time. These surveys were made during the various seasons of each of the 2 years of the service life of the pavement. Figure 9 shows the location of cracks in a 1,070-foot section reinforced with 1-inch diameter billet steel bars; figure 10 shows data for sections 90, 150, and 330 feet in length reinforced with ½-inch diameter steel bars; and figure 11 shows data for sections 20, 30, 40, 50, 60, 80, 100, and 120 feet in length containing three different weights of welded wire fabric reinforcement as noted.

Referring to figure 9, it will be noted that numerous cracks have formed in the central area of this long, heavily reinforced section. In this area cracks are frequently less than 2 feet apart, but near the ends the spacing gradually becomes much greater. This manner of cracking was anticipated. The cracks are barely visible even on very close inspection and none has opened sufficiently to indicate an inelastic elongation of the steel. At this time there is no spalling or disintegration and the section is structurally intact. Figure 12–A is a recent photograph of a crack typical of those that formed early in the life of this section.

In the intermediate-length sections shown in figure 10 containing much less reinforcement, the number of cracks that have formed in a given length is much smaller than that found in the longer, more heavily reinforced sections. Of the three sections represented in figure 10, only the 330-foot section has an appreciable number of cracks discernible at this time. In the 150-foot section only one crack has formed and the 90-foot section contains no full length cracks. The cracks in

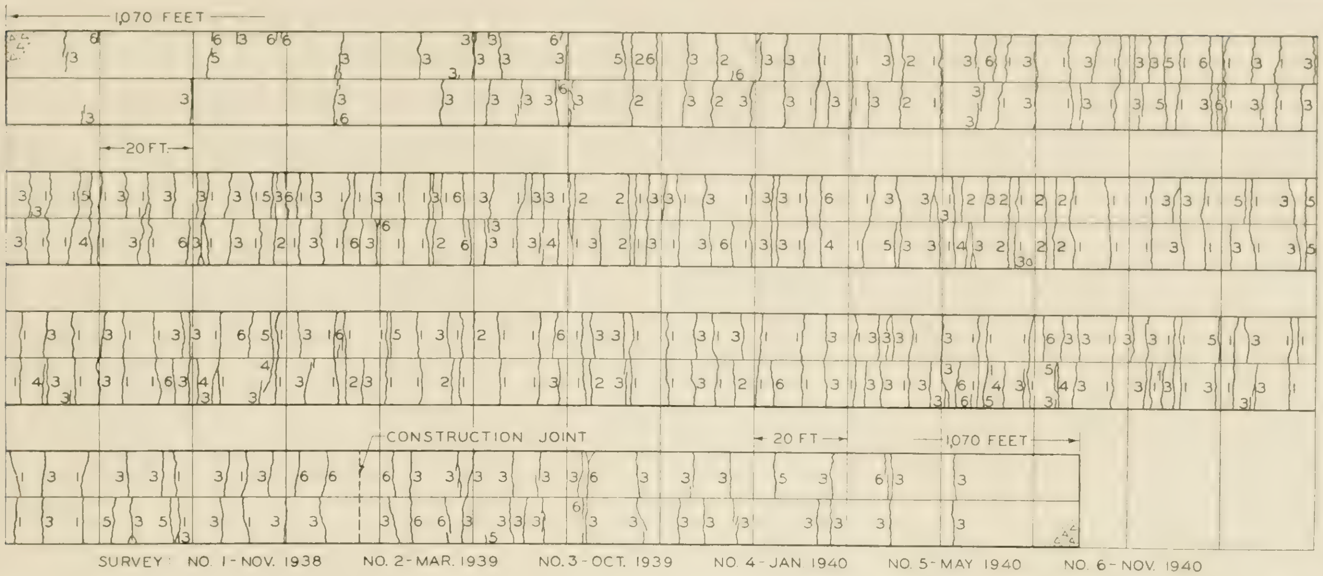



FIGURE 9.—TYPICAL CRACK SURVEY SHEET FOR LONG SECTIONS REINFORCED WITH 1-INCH DIAMETER STEEL; SECTIONS PLACED SEPTEMBER-OCTOBER, 1938.

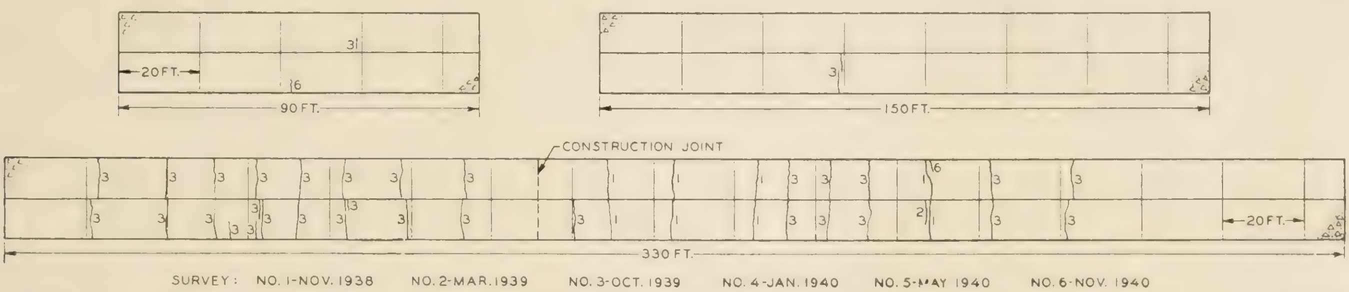



FIGURE 10.—TYPICAL CRACK SURVEY SHEET FOR INTERMEDIATE-LENGTH SECTIONS REINFORCED WITH ½-INCH DIAMETER STEEL; SECTIONS PLACED SEPTEMBER-OCTOBER, 1938.

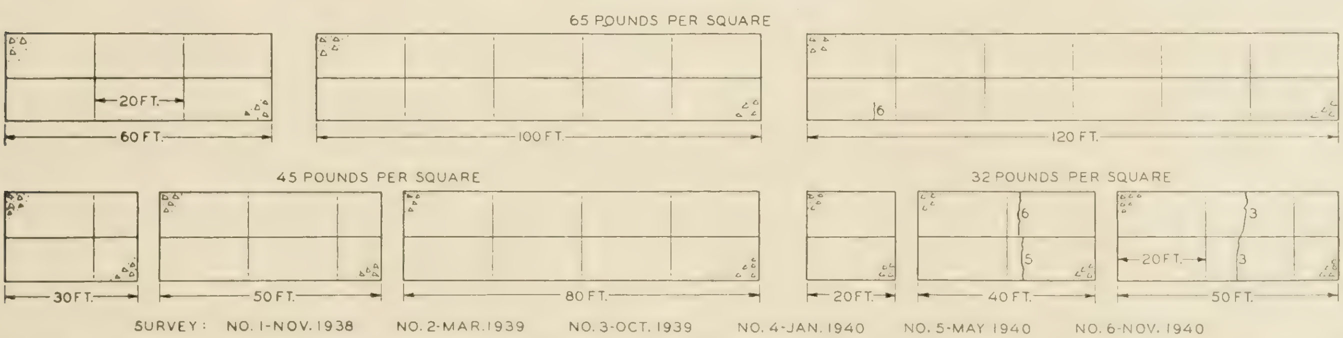



FIGURE 11.—TYPICAL CRACK SURVEY SHEET FOR SHORT SECTIONS REINFORCED WITH WELDED FABRIC; SECTIONS PLACED SEPTEMBER-OCTOBER, 1938.

the intermediate-length sections appear to be slightly more open than those in the more heavily reinforced sections, but the difference is slight and no quantitative data are available at this time. There is no spalling, disintegration, or evidence of inelastic deformation of the steel in these sections. Figure 12–B shows the present appearance of a typical crack in this part of the pavement.

As will be noted from figure 11, little or no cracking has occurred to date in the shorter sections reinforced with welded wire fabric. Of the nine sections represented in this figure only two have cracked across the full width of the slab. These are the 40- and 50-foot sections reinforced with the 32-pound fabric, the lightest weight used. Figure 12–C shows the present appearance of one of these cracks. The cracks are open slightly but there is no spalling, disintegration, or evidence of steel failure.

Comparison of figures 9, 10, and 11 indicates the existence of a relationship between the average slab length, or number of cracks, and the length of the sections, or amount of longitudinal reinforcement. A study has been made of this relationship and in figure 13 is shown the relation between length of section and the average slab length as found in March 1939 and again in November 1940. The sections represented

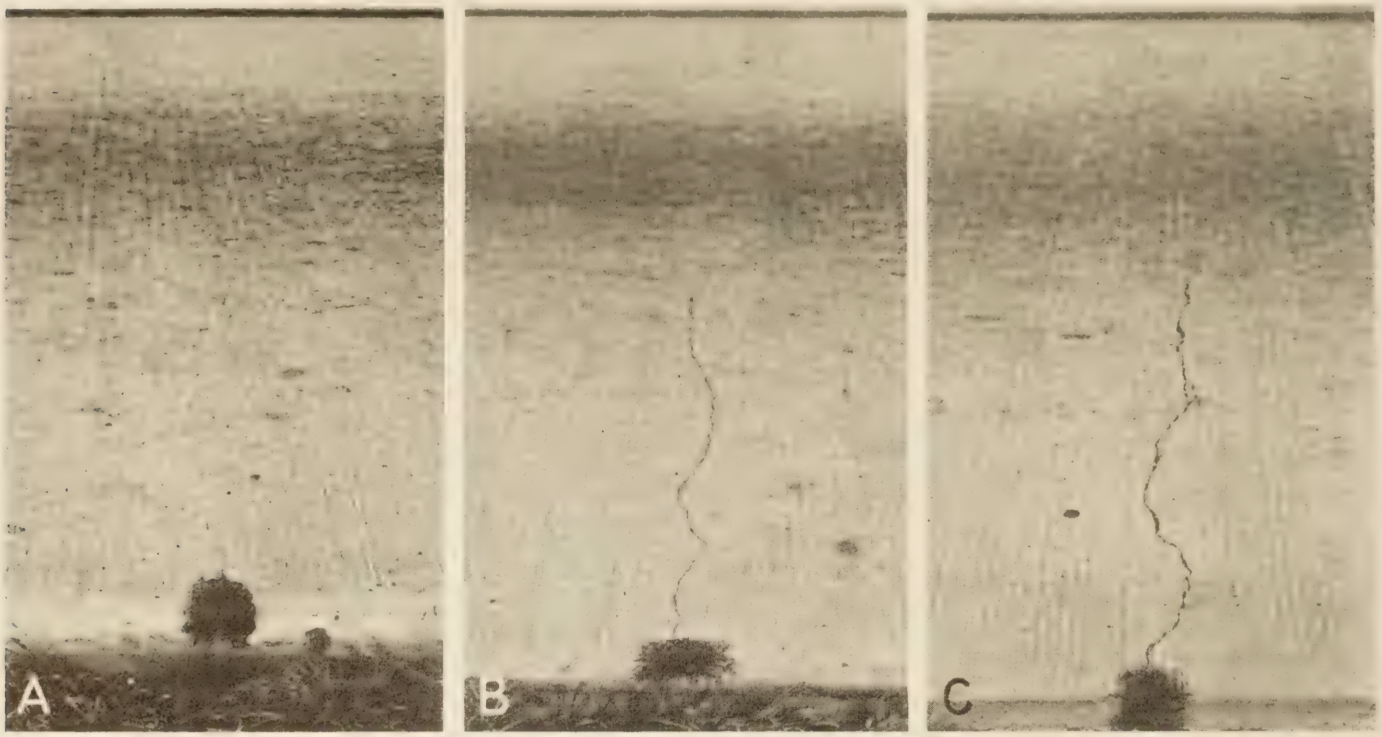



Figure 12.—Typical Cracks in: A, Long Section Reinforced with 1-inch Diameter Bars; B, Intermediate-length Section Reinforced with ½-inch Diameter Bars; and C, 30-foot Section Reinforced with 32-pound Wire Fabric.

in this graph include three sizes of bar reinforcement and several weights of welded wire fabric. As in other figures, the points for the first survey have been omitted for the sake of clarity.

At the time of the March 1939 survey little or no cracking was found in sections having lengths of 210 feet or less. In sections longer than 210 feet cracking occurred and the frequency, as indicated by the average slab length, increased rapidly with increase in section length. For example, at the time of this survey the average uncracked slab length of the 250-foot sections was approximately 120 feet, that for the 600-foot sections was about 16 feet, and that for the 1,070-foot sections was about 13 feet.

By November 1940 a considerable change had occurred. The average length of the uncracked slabs had been reduced to about 130 feet. The average slab length of the 250-foot sections had been reduced to about 23 feet, the 600-foot sections to about 10 feet, and the 1,070-foot sections to about 6 feet.

While it might be inferred from figure 13 that the average slab length is not influenced by the amount of longitudinal steel present, it is believed desirable to await further developments before attempting to draw any conclusion regarding this point.

#### SUBGRADE RESISTANCE CAUSED CRACKING IN LONG SECTIONS

Figure 14 shows the manner in which the cracking developed in the sections of various lengths with respect to time of year. The long sections shown are reinforced longitudinally with 1-inch diameter bars, the intermediate sections with ½-inch diameter bars, while the short sections contain the three lighter weights of welded fabric (32, 45, and 65 pounds per square). The condition at the time of each of the six surveys is shown. The first survey was made after the completion of the curing period and within about 1 month after the section was laid. At this time about 40 percent of the cracking that now exists was present in the long sections and about 20 percent in the intermediate-length sections. By March 1939 there had been but little change although the pavement had passed through a winter.

The survey in October 1939 showed a very great change in all groups. Since October 1939 there has been only a gradual increase in the number of cracks in all of the sections. The rate of cracking during this period has been greater for the shorter sections, although so few cracks have occurred that this is probably not significant. Figure 14 indicates that the severe freezing of December 1939 and January 1940 had no noticeable influence on the rate of cracking.

The tensile stress in the concrete caused by the resistance offered by the subgrade is apparently responsible for most of the cracking that has occurred in the longer sections. This is indicated by the fact that comparatively little cracking has developed thus far in either the shorter sections or in the ends of the longer sections. In long slabs reinforced with continuously bonded longitudinal steel, the tensile stresses in the concrete caused by subgrade resistance are relieved when a crack or rupture occurs. The forces that caused the stresses are transmitted across the rupture plane by the steel and are transferred back to the concrete by the bond between it and the steel. The distance required for this transfer depends upon the magnitude of the force and the quality of the bond available. This explains why cracks have formed at such close intervals in the long sections with large amounts of reinforcement and at greater intervals in the shorter sections containing relatively small amounts of reinforcement.

Because the pavement was laid in the fall of the year, it might be expected that, in the long sections that are restrained, there would be a residual compressive stress during the summer when the temperature rises above

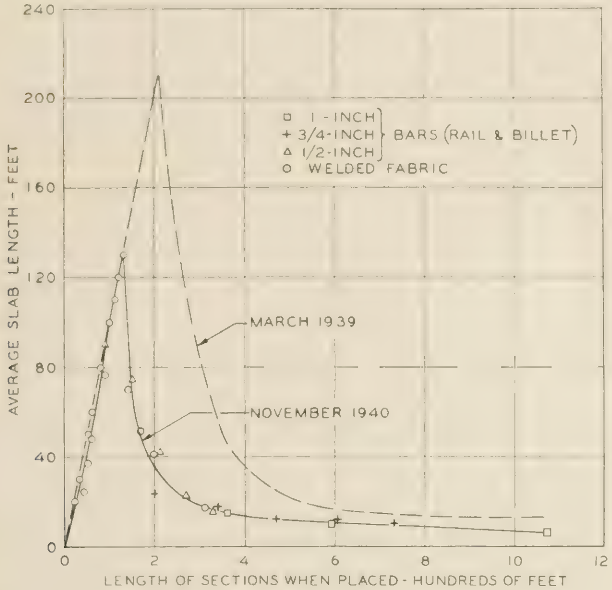



FIGURE 13.—RELATION BETWEEN LENGTH OF SECTION AND AVERAGE SLAB LENGTH.

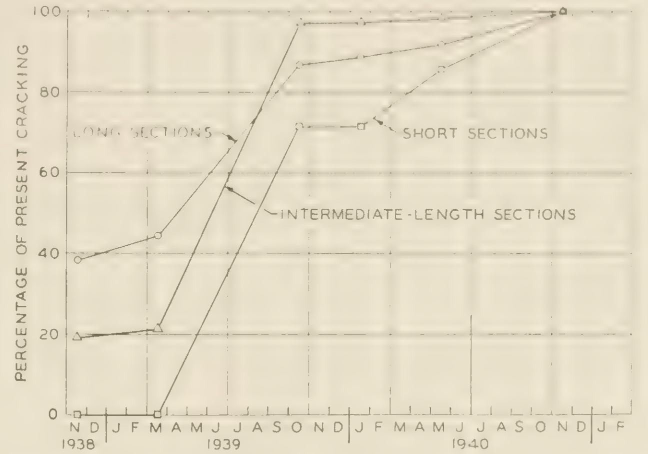



FIGURE 14.—RATE OF CRACK DEVELOPMENT IN PAVEMENT SECTIONS.

that at which the concrete was placed and a corresponding residual tensile stress when the temperature falls below that point during the winter. This being the case, it is natural to expect that cracking from subgrade restraint would develop during the winter. It was shown by figure 14 that the greater part of the cracking was found after the hot weather of summer, rather than after the cold weather of winter as might have been expected. It is possible that incipient cracks started during the winter do not become discernible for some months. Whether or not this is true has not been established. It is possible that the residual stresses mentioned above would be relieved by plastic flow. If this happened, the highest tensile stresses would probably be the combined stresses that develop during the daily temperature cycle in the summer months.

The occasional cracking that has developed in the shorter sections and in the end areas is probably the result of combined load and warping stresses, as the restraint of the subgrade could not produce critical tensile stress in sections of such length. Also the cracking in the shorter sections apparently occurred during the summer when warping stresses are high.

#### SPECIAL STUDY MADE OF SECTIONS CONTAINING PLANE-OF-WEAKNESS JOINTS

In connection with the study of cracking of the various sections of the experimental pavement, an opportunity has been afforded to observe the influence of traffic on the development and condition of the cracks. This 2-lane pavement is one-half of a dual highway; consequently, the right-hand lane carries the greater number of vehicles and practically all of the heavy trucks, the left-hand lane being used largely for passing. While it might be argued that the two slabs are tied together at the center joint and thus cannot act independently, still it would be expected that if heavy traffic played an important part in the development of the transverse cracking, some difference in the condition of the two lanes would exist. None has been found.

It will be recalled that in the experimental pavement were four sections each 500 feet in length, in which contraction or warping joints were placed at 10-foot intervals. Two of these sections contained 45-pound wire fabric; the other two contained 91-pound fabric. The fabric was continuous through the warping joints although the bond was broken for 36 inches. These joints were planes of weakness formed by grooves in the bottom of the pavement in two sections and in the upper surface in the other two sections.

A record was kept of the time at which the cracks appeared over the grooves that had been formed in the bottom of the pavement, and this record is shown in figure 15. It is noted that only two cracks were found at the time of the removal of the burlap and only two more during the remainder of the curing period. The others occurred gradually until by the end of the first year fractures had developed at all of the joints.

Measurements are being made periodically of the changes in width that take place, both at the expansion joints and at the warping joints, in these 500-foot sections. From these measurements certain trends have been observed.

1. The weakened-plane joints near the center of the section open and close slightly with temperature changes but there appears to be no tendency for progressive increase in width.

2. The weakened-plane joints near the ends of the sections show a tendency toward a progressive increase in width. This tendency seems to be greater in the sections with the groove in the lower surface of the pavement than in those that have the grooves in the upper surface.

3. There seems to be a tendency toward a progressive closing of the expansion joints. This tendency is apparently more pronounced in the sections containing the lighter reinforcement.

The changes in length of each of the four 500-foot sections as measured at the ends for the two annual cycles are given in table 6.

The changes in length are not caused entirely by variation in temperature and moisture because, as stated, there has been a slight progressive opening of some of the plane-of-weakness joints. It will be noted in this table that the change in temperature during the first year was smaller than that during the second and that there is a difference in the length changes of the same general order. Using the coefficient of 0.000004, as explained earlier, the observed changes in length of these 500-foot sections indicate that a certain amount

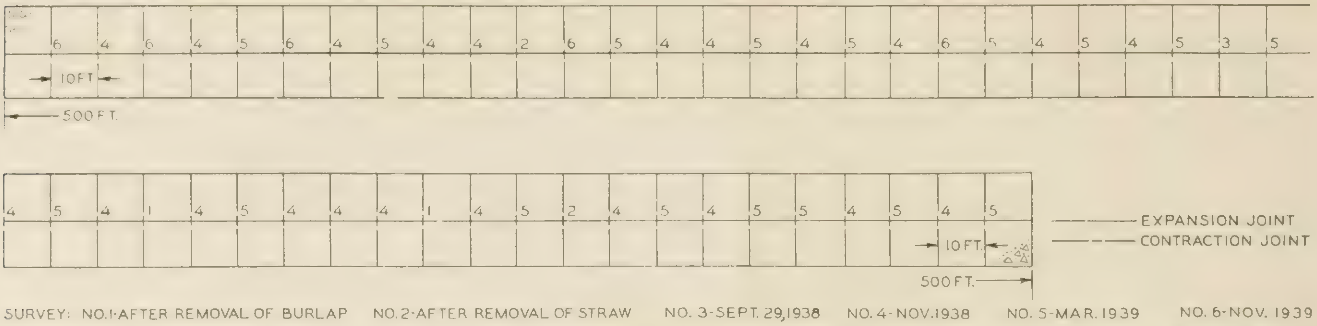



Figure 15.—Progressive Cracking of Submerged Plane-of-Weakness Contraction Joints; Section Placed September 8, 1938.

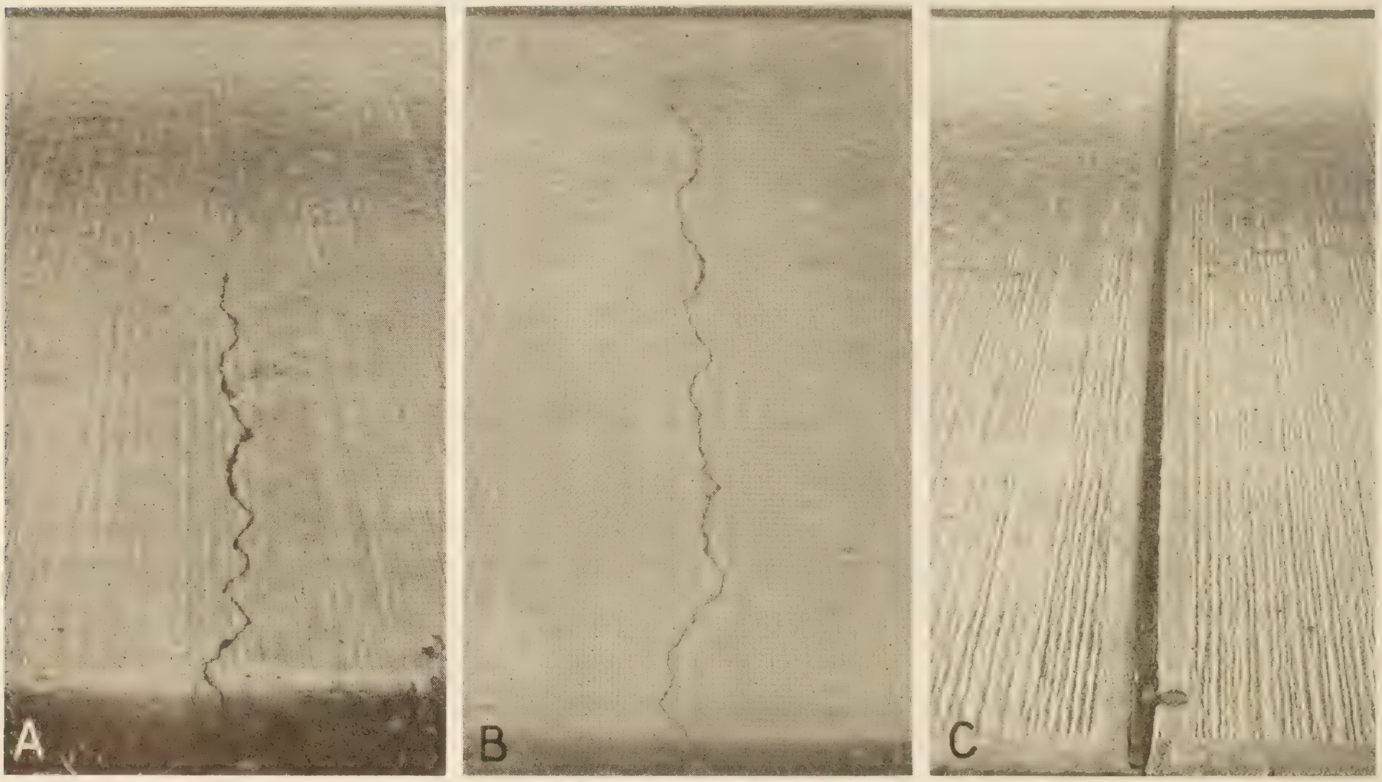



Figure 16.—A, Typical Crack Over Submerged Parting Strip in Lane Carrying Heavy Traffic; B, Typical Crack Over Submerged Parting Strip in Lane Carrying Light Traffic; C, Present Condition of Typical Weakened-Plane Joint With Surface Groove.

of restraint was present during expansion and contraction.

Figure 16 shows the appearance of cracks over the submerged grooves in the right-hand and the left-hand lanes. These cracks have opened slightly and the edges have become slightly rounded. This condition is more noticeable in the right-hand lane.

Those weakened-plane joints formed under a groove in the upper surface appear to be in perfect condition at this time. Figure 16–C shows the present condition of one of these joints.

Table 6.—*Annual changes in length of 500-foot sections with weakened-plane joints at 10-foot intervals*

| Section No. | Weight of reinforcement | Type of weakened-plane joint | Time of observation | | Temperature difference | Change in length |
|---|---|---|---|---|---|---|
| | | | Winter | Summer | | |
| | *Lb. per sq.* | | | | *°F.* | *Inches* |
| 1 | 91 | Submerged | 1938–1939 | 1939 | 60 | 1.10 |
| | | | 1939–1940 | 1940 | 84 | 1.47 |
| 2 | 45 | do | 1938–1939 | 1939 | 60 | 1.33 |
| | | | 1939–1940 | 1940 | 84 | 1.41 |
| 3 | 91 | Surface | 1938–1939 | 1939 | 60 | .74 |
| | | | 1939–1940 | 1940 | 84 | 1.23 |
| 4 | 45 | do | 1938–1939 | 1939 | 60 | .83 |
| | | | 1939–1940 | 1940 | 84 | 1.05 |

#### SURFACE ROUGHNESS OF THE SECTIONS COMPARED

Recently a new instrument for indicating the relative roughness of road surfaces has been developed by the Public Roads Administration. The roughness of the surface is indicated by an index expressed in inches per mile of pavement length. With this apparatus it is possible to compare the surface roughness of sections of various lengths. The device was described in the February 1941 issue of Public Roads.

The relative roughness index of the heavily traveled lane as determined during August 1940 for the various

(*Continued on p. 65*)

# THE APPLICATION OF ROAD-USE SURVEY METHODS IN TRAFFIC ORIGIN AND DESTINATION ANALYSIS

BY THE DIVISION OF CONTROL, PUBLIC ROADS ADMINISTRATION [1]

Reported by T. M. C. MARTIN, Assistant Highway Engineer-Economist, and HOMER L. BAKER, Assistant Transportation Economist

DATA relative to motor-vehicle travel are in general procured in two ways. The first is that method to which the name "traffic survey" has been applied. The second method is that which has come to be designated by the term "road-use survey."

Traffic surveys embody many ramifications but there is one characteristic which differentiates them from the second method of evaluating motor-vehicle travel. Traffic surveys involve the actual observance of the vehicles at some point of their travel on a given trip, whereas the road-use surveys depend upon interviews with the owners of motor vehicles. In the traffic survey the observance of the vehicle at one or more points in a particular trip may be supplemented by questioning the driver concerning that particular trip. The road-use surveys depend upon interviews with the owners of motor vehicles during which a complete enumeration is made of all or a large part of the travel performed in the vehicles of the interviewed owners throughout a specified period of time, usually 12 months.

Most early traffic studies were made by observing the movement of vehicles past a station located usually at the junction of two or more highways. Traffic surveys have grown in scope and many corollary types of information are now collected. The gathering of some of these data necessitates the stopping of vehicles. This is necessary, for example, where the physical dimensions and weights of commercial vehicles and the nature of the commodities transported are subjects of inquiry. Lately another type of information pertaining to vehicle movement has been found useful in traffic analyses. This information concerns the origin and destination of individual trips by vehicles engaged in both private and commercial transportation, and likewise requires the stopping of traffic. Special origin-and-destination surveys have also been made by most of the States participating in the highway-planning surveys. These studies have usually been localized to a relatively restricted section of highway and have yielded information relating only to the travel of vehicles over the specified section of highway or within a limited area.

The road-use survey embodies certain features which suggest the possibility of using the data obtained in interviews to make State-wide origin-and-destination travel analyses. Actually, the origins and destinations of as many as possible of the trips made by a selected sample of motor-vehicle owners are determined and recorded in the road-use survey. The road-use survey interview form provided for the recording of a complete description of each type of trip made during the year, including the routes followed, the destinations reached, and the mileage traveled.

One of the earliest attempts to obtain travel data by questioning drivers concerning the number and extent of their trips was made in Wisconsin about 1916 under the direction of A. R. Hirst, State highway engineer. A reference to this work was made in the Third Biennial Report of the Wisconsin Highway Commission, 1916, as follows:

> A careful inquiry (through written question sheets) among automobile owners indicates that the average distance traveled by each automobile is at least 3,500 miles per year on roads outside the limits of incorporated cities and villages. If we estimate 140,000 pleasure cars in use in Wisconsin next year, which seems conservative, and each travels this number of miles, the motor travel on Wisconsin rural highways will be 490,000,000 miles. This does not take into consideration the travel of automobiles from other States.

#### ROAD-USE SURVEYS HAVE BEEN MADE IN 44 STATES DURING RECENT YEARS

Since 1930, road-use surveys have been made in 44 States, the majority having been conducted between 1936 and 1940. Two methods of obtaining the driver interviews were used in these surveys. The first of these methods employed parties of full-time salaried interviewers; while the second method was based upon the collection of interviews through the public schools. In the latter method, high school pupils were instructed in the procedure used to obtain driver interviews. The usual practice was to have each student obtain an interview based upon the travel of the family automobile and if possible an extra interview from a friend or neighbor. Excellent results were obtained with both methods.

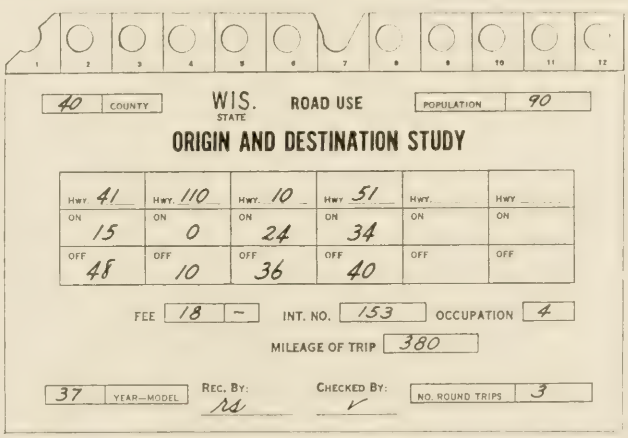



FIGURE 1.—TABULATING CARD USED TO RECORD INDIVIDUAL TRIP DATA.

The results of these surveys have been published by many of the States in complete form while others have used the road-use data in preparing special reports including other related data.

In order to investigate the potentialities of road-use methods for origin-and-destination analyses, a special study was instituted using data collected by the Wis-

[1] Acknowledgment is made to the personnel of the Wisconsin Highway Planning Survey for their cooperation in supplying data for this report.


Figure 2.—Average Daily Passenger-Car Traffic on Wisconsin State Trunk Highways.

consin State-Wide Highway Planning Survey in 1936. The scope of this particular inquiry was limited to cover the destination of passenger-car travel performed on State highways by owners resident within the corporate limits of the City of Milwaukee. The analysis was made of only those trips which extended beyond the limits of Milwaukee County. The boundaries of Milwaukee County are slightly outside those of the City on the north, south, and west. On the east the two share Lake Michigan as a common boundary.

The areas contiguous to the city within the county have become generally urban in character, and the travel upon State highways in these areas has assumed many of the characteristics of city travel, including among other attributes a certain amount of indefiniteness. This may be illustrated by the large number of pleasure trips that involve the use of State highway route 100 which in reality is a county belt highway located outside the city but passing entirely around it and connecting all radial routes, both State and local.

By excluding travel within Milwaukee County, it was possible to eliminate virtually all trips that were sparingly described, such as, "Sunday afternoon drive—Doctors' Park, River Hills, Pewaukee, Club Madrid, etc., 40 miles." The trips on the primary system which were tabulated in this study were all definite in the sense that they (1) originated within the City of Mil-

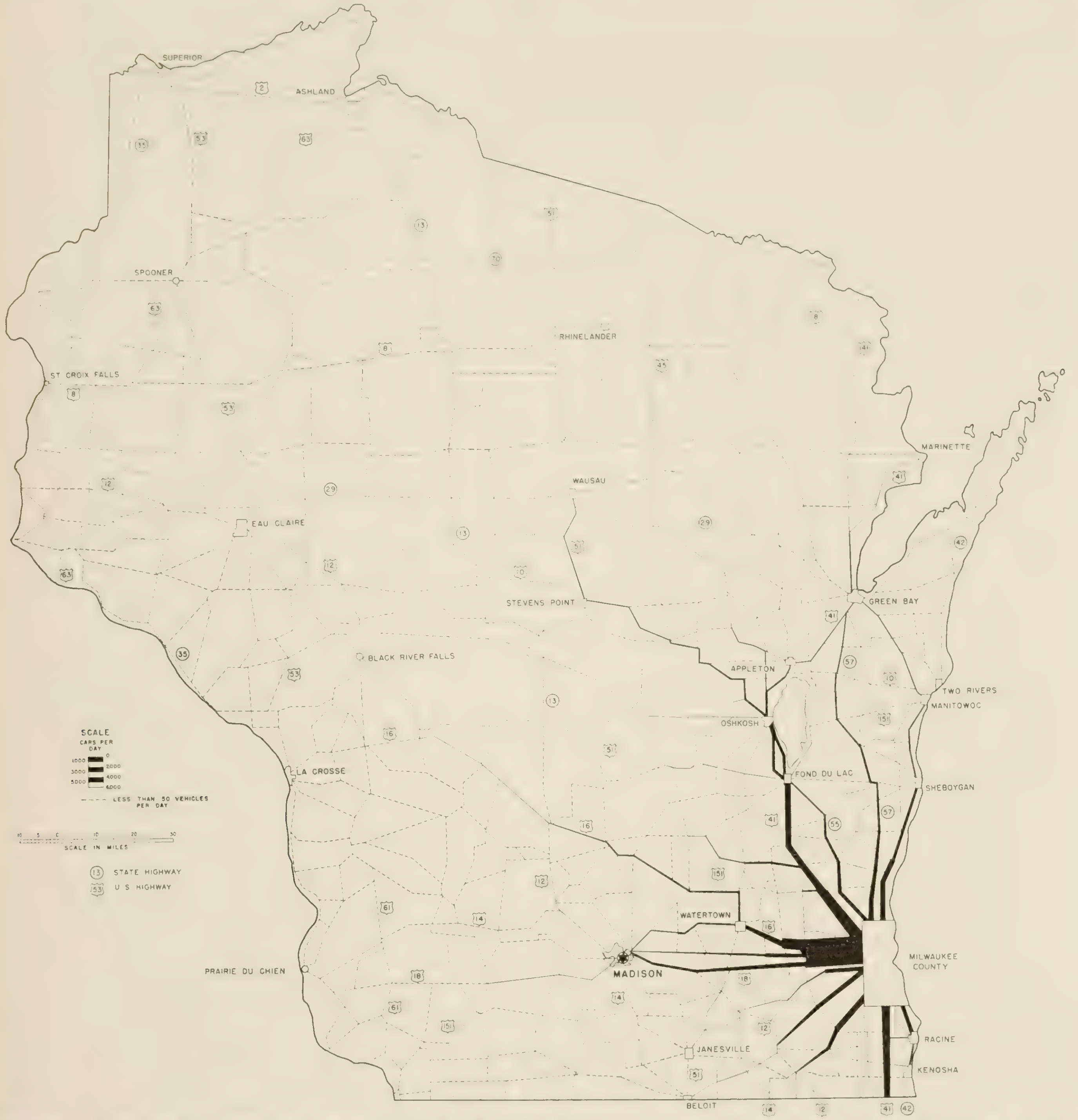



Figure 3.—Average Daily Traffic on Wisconsin State Trunk Highways by Passenger Cars Owned by Residents of the City of Milwaukee.

waukee, (2) extended beyond the limits of Milwaukee County, and (3) left Milwaukee County on a State highway. No attempt was made to distinguish between the State highway route numbers followed within Milwaukee County; the route a vehicle was following when it left Milwaukee County was the one credited with the travel. This procedure was considered reasonable since various marked routes within the City of Milwaukee would be used. The particular streets which could be used by persons traveling from Milwaukee to Fond du Lac on U. S. route 41, for example, would depend largely upon the particular part of the city from which the trip was started. Thus, a person living on the east side might follow Prospect Avenue to Maryland Avenue to Capitol Drive to U. S. route 41, whereas a resident of certain west-side sections might elect to go out Fond du Lac Avenue to Capitol Drive to U. S. route 41. Numerous other routes are followed, since residents pay little heed to the marking system, but use the roads, city, county, or State, which provide the most direct egress from the county.

In order to facilitate the tabulation of the required information from the original road-use forms used in the planning survey, a special tabulating card was designed. This card, which is illustrated in figure 1, provided for a codified recording of the essential data pertaining to each type of trip performed by Milwaukee vehicle owners. A log was prepared of each State highway in Wisconsin, and all junctions of both State and county roads with each State route were numbered to provide a code for the recording of the junctions passed on a given trip. Thus, a trip from Milwaukee to Wausau, Wisconsin, via U. S. route 41 to Oshkosh, thence U. S. route 110 to Fremont, thence U. S. route 10 to Stevens Point and U. S. route 51 to destination would be recorded as shown in figure 1. Since the junctions were numbered starting from the south and east, this would mean merely that Milwaukee was the 15th junction on U. S. route 41, Oshkosh the 48th junction on U. S. route 41 and the zero junction on U. S. route 110, Fremont the 10th junction on U. S. route 110 and the 24th on U. S. route 10, Stevens Point was the 36th junction on U. S. route 10 and the 34th on U. S. route 51, while Wausau was the 40th junction on U. S. route 51.

#### ANALYSIS INDICATES EXTENSIVE USE OF ALL STATE ROUTES BY MILWAUKEE RESIDENTS

The recording of information regarding route junctions in this manner greatly facilitated the operations necessary in making trip origin-and-destination analyses. All that was required following the recording of trip information on these cards was an orderly sorting and tabulating procedure whereby the number of trips performed over various sections of the State highway system could be ascertained. In this particular analysis, only the travel on the State system was the subject of inquiry and consequently the "destination" was the point at which the route followed departed from the State highway system either to city streets or to local rural roads.

The Milwaukee road-use survey included in its passenger-car sample reports from 2,387 vehicles. The total number of passenger vehicles registered in the city at the corresponding period was 113,342. The method of expanding the trip information obtained from the sample involved the application of the following formula:

$$\frac{\text{Number of trips}}{\text{(from sample)}} \times \frac{\text{total passenger car registration}}{\text{passenger cars in sample}} = \text{esti-}$$

mated total trips for complete passenger-car registration.

Two maps have been prepared to illustrate the data obtainable from this type of analysis. The first map, figure 2, is based upon the regular traffic volume studies conducted by the Wisconsin highway-planning survey. The map shown in figure 3 was prepared from trip-destination data from the special road-use tabular cards described above. The first map represents the use of Wisconsin State highways by all passenger cars, both of Wisconsin and foreign registration, and without regard to their owners' residential classification. The second map represents the travel upon the same State highways by passenger cars having Wisconsin registration and owned by residents of the City of Milwaukee.

Many of the roads shown in the second map carried less traffic than could be accurately shown at a scale in keeping with permissible over-all dimensions. It was necessary to distinguish, therefore, the point at which the traffic became so small that the width of the line prevented accurate graphical representation. This was taken to be a volume of 50 cars per 24 hours. Consequently, the dotted lines represent average annual 24-hour traffic of less than 50 passenger cars.

These maps illustrate the extensive use of the State highway system and emphasize the intensive use of those roads lying within a comparatively short distance of Milwaukee. The extensive use of the entire primary system by residents of Milwaukee indicates the widespread distribution of points of interest for trips originating in Milwaukee. The location of many urban centers of varying importance to Milwaukee residents within a radius of 85 miles tends to make the highways within that distance of more importance to Milwaukee drivers than those highways which lie at greater distances from the city. Cities of major importance to Milwaukee drivers which lie near the extremities of this 85-mile radius are Chicago, on U. S. route 41, Madison, on U. S. route 18, and Oshkosh on U. S. route 41. Figure 3 indicates that Milwaukee drivers make extensive use of these routes to reach these cities.

While travel to these larger cities accounts for a large proportion of the total use of the primary system, the number of trips to these places is far exceeded by the number of trips to points relatively close to Milwaukee. Figure 4, which is an enlargement of the area lying within a 50 mile radius of Milwaukee and based on figure 3, illustrates the intensive use of the State highways within a 30-mile radius of the City and the rapid decrease in the volume of Milwaukee passenger cars using these highways at points more than 30 miles from the City.

Figure 5, is an enlargement of the area lying within a 50-mile radius of Milwaukee, and is based upon the total passenger-car traffic on State trunk highways.

#### STUDY INDICATES THAT LARGE PROPORTION OF ANNUAL TRAVEL CONSISTS OF RELATIVELY SHORT TRIPS

Several recreational areas within a 40-mile radius of Milwaukee are visited frequently by residents of that city. The proximity of numerous lakes is an important factor in the use of rural highways in the vicinity of Milwaukee. Many Milwaukee residents have established summer homes in this lake region, which lies within 30 miles of the city. A large proportion of travel to nearby points is occasioned by trips to these summer residences and by evening and week-end trips to resorts. The influence of these factors is illustrated by the rapid decline in the amount of traffic on the principal routes at points 20 to 30 miles from the city. These factors exert the greatest influence on travel on routes leading to the area lying west and southwest of Milwaukee.

Travel to Chicago by Milwaukee residents probably accounts for the relatively uniform use of U. S. route 41 from Milwaukee to the State line. Similarly, this same route leading to Fond du Lac and Oshkosh north of Milwaukee does not show a rapid decline in the volume of traffic at points close to the city. This is the principal route leading to these important cities and it also carries a large volume of traffic to the recreational areas in the northern lake region.

Figure 3 presents a reasonably accurate picture of the use of the State primary system by Milwaukee residents. A comparison of this map with figure 2

*(Continued on p. 66)*

# METHOD OF COMPUTING THE INTERSECTION OF A LINE WITH A SPIRAL AND ANY CURVES PARALLEL TO THE SPIRAL

Reported by M. C. KOEHLER, Senior Engineer Inspector Foreman, District 1, Public Roads Administration

SINCE the adoption of the spiral or easement curve in highway design and construction, the problem of computing the intersection of a line with such a curve, and its parallel right-of-way lines, has persistently presented itself in the computation of property line ties preparatory to the preparation of right-of-way descriptions. Various approximate methods have been proposed from time to time, but like all approximate methods are unsatisfactory if an exact solution is possible.

Although the solution presented in the following paragraphs is not exact in a strictly theoretical concept, it is an exact solution from a practical standpoint since the results are within the limits of measurement possible with standard engineering instruments.

In figure 1, assume CA to be a property line intersecting a talbot spiral BD, the intersection occurring at point A. The solution is then of triangle ABC of which the following is known:

Distance CB which has been determined by the coordinates shown or 776.68 feet.

Angle $\alpha$ which is determined from the bearings of line CA and CB or 7°09.5′.

Now scale chord BA attempting to choose the length to the nearest foot just short of the exact length. In this case try 228 feet.

Since the chord length has been assumed, and knowing the characterstics of the spiral shown in figure 1, now compute angle $\phi$ which is 25°03.3′.

By the law of sines:

$$BA=\frac{776.68\times\sin 7°09.5'}{\sin 25°03.3'}=228.55>228.$$

Now try the chord 229 feet.

$$BA=\frac{776.68\times\sin 7°09.5'}{\sin 25°03.9'}=228.47<229.$$

These results are shown in table 1, together with values found for chords 227 and 230 feet.

It is thus found that the true chord length is something between 228 and 229 feet and always occurs between the two chords where the difference between the assumed chord and the computed chord changes sign. It should also be noted that even though the assumed chord were scaled several feet from its true value, the computed chord always calculates within a few tenths of the true value, materially reducing the number of trials to be made in isolating the true length within a foot.

TABLE 1.—*Differences between assumed and computed chords*

| Assumed chord | Computed chord | Difference |
|---|---|---|
| 227 | 228.64 | +1.64 |
| 228 | 228.55 | +0.55 |
| 229 | 228.47 | −0.53 |
| 230 | 228.38 | −1.62 |

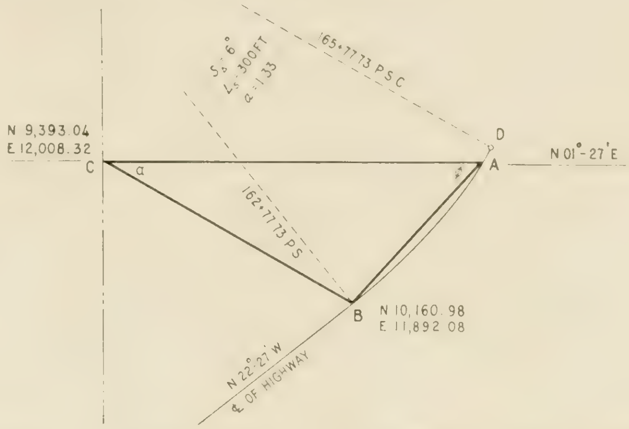



FIGURE 1.—INTERSECTION OF A LINE WITH A SPIRAL CURVE.

By interpolation, it is possible to compute the true chord which will close triangle ABC.

$$228+\frac{0.55}{0.55+0.53}=228.51.$$

Proof:

$$BA=\frac{776.68\times\sin 7°09.5'}{\sin 25°03.6'}=228.51.$$

The further solution of triangle ABC gives:

$$CA=\frac{776.68\times\sin 32°13.1'}{\sin 25°03.6'}=977.61.$$

From any table of spiral data it is found that the arc distance is 0.04 foot longer than the chord 228.51.

Therefore 228.51+0.04=228.55 feet and the station of intersection is:

P. S. 162+77.73+228.55=165+06.28 and bears N 01°27′ E a distance of 977.61 feet from the property corner.

#### INTERSECTION WITH CURVES PARALLEL TO SPIRAL COMPUTED

In figure 2, assume an inside right-of-way line, always 50 feet from and parallel to the talbot spiral, intersecting the property line at point C. In triangle ABC the distance CB, which is 50 feet, is known.

As before scale chord BA using 103 feet for the first trial.

Now 228.55−103.00=125.55 feet which is assumed to be the chord from the P. S. (point of spiral) to point B. From this chord compute the bearing of the local tangent at point B and then compute the bearing of the normal to this tangent which is CB. Taking the difference in bearings of CB and CA, angle $\alpha$ is found to be 65°03.0′.

By the method of computing the deflection from any point on a spiral to any other point on the spiral, compute the bearing of BA. Taking the difference in bearings between BA and CA angle $\phi$ is found to be 26°03.0′.

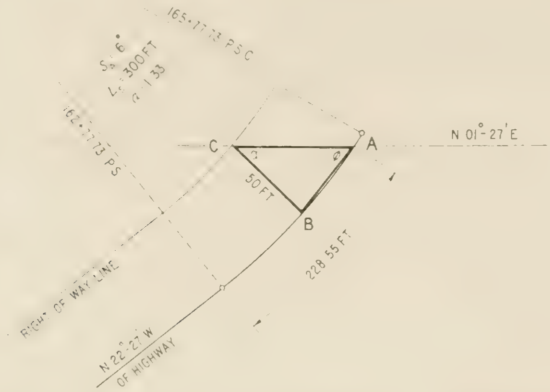



FIGURE 2.—INTERSECTION OF A LINE WITH A CURVE INSIDE AND PARALLEL TO A SPIRAL CURVE.

By the law of sines:

$$AB=\frac{50\times\sin 65°03.0'}{\sin 26°03.0'}=103.23>103.$$

Now try the chord 104.

$$AB=\frac{50\times\sin 65°03.5'}{\sin 26°02.7'}=103.26<104.$$

By interpolation the chord which will close triangle ABC is found to be 103.24.

$$\text{Proof:}\quad AB=\frac{50\times\sin 65°03.2'}{\sin 26°02.8'}=103.24.$$

The further solution of triangle ABC gives:

$$CA=\frac{103.24\times\sin 88°54.0'}{\sin 65°03.2'}=113.84.$$

Therefore 977.61−113.84=863.77 feet from the property corner and is 50 feet at right angles from centerline station 164+03.05.

Figure 3 shows the outside right-of-way line which intersects the property line at point D. It is evident that this intersection is not on the parallel spiral but occurs on the parallel simple curve and the solution is by coordinates and triangulation, resulting in the solution of triangle COD by the following method:

Starting with the coordinates of point B compute the coordinates of point E and then point O, which is the center of the simple curve. From the coordinates of point O and C, OC is found to bear N 74°12.2′ W and is 1,317.02 feet long, making angle $\alpha$ 75°39.2′.

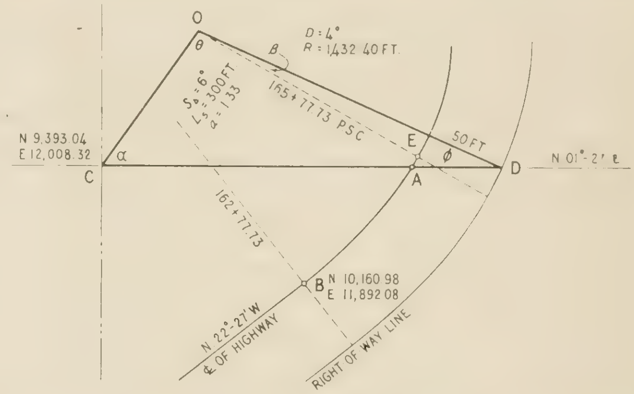



FIGURE 3.—INTERSECTION OF A LINE WITH A CURVE OUTSIDE AND PARALLEL TO A SPIRAL CURVE.

Side OD is equal to the radius of the simple curve (1,432.40) plus 50 feet or 1,482.40 feet, and by the law of sines angle $\phi$ is 59°23.9′ and angle $\theta$ is 44°56.9′.

$$\text{Therefore } CD=\frac{\sin 44°56.9'\times 1317.02}{\sin 59°23.9'}=1{,}080.98 \text{ feet}$$

which is the distance from the property corner C to point D on the right-of-way line. From the bearings of OE and OG angle $\beta$ is found to be 0°42.1′ which subtends 17.54 feet on the arc of the 4° simple curve and point D is 50 feet at right angles from centerline station 165+95.27.

In these computations it will be noted that all angles have been carried out to tenths of a minute. This has been found necessary to make all lineal distances calculate to the nearest one hundredth of a foot.

There are many other combinations of property lines intersecting spirals which are not presented in the above problem, but all are solvable by the method outlined. One point should be borne in mind; always choose a triangle in such a manner that one side is a chord of the centerline spiral, since the characteristics of that curve are known. Distances and angles may be computed to any point on the parallel spiral, but the exact characteristics of the parallel spiral itself are still open to solution.

## NATURAL-COLOR SLIDES OF MERRITT PARKWAY AVAILABLE

A film book composed of natural-color slides of aerial pictures and script covering the story of the Merritt Parkway, including its connection down to New York through the West Side Highway, has recently been completed. Prepared by the Yale University Bureau for Street Traffic Research in cooperation with the Connecticut Highway Department, the film book is called "Roads Leading North."

In addition to the 84 2- by 2-inch slides with accompanying script, there is a technical trailer consisting of over 20 slides and script dealing with engineering detail, accident experience, and the volume and speed of vehicles. The slides may be shown on any 2- by 2-inch projector.

"Roads Leading North" is available on loan without charge other than transportation from and to Yale University or nearby depository, to any highway department, highway commission, traffic engineering department, or similar organization dealing with highway problems. Requests for the film book should be addressed to: Bryant Burkhard, Yale Bureau for Street Traffic Research, Strathcona Hall, Yale University, New Haven, Conn.

(Continued from p. 58)

sections of the experimental reinforced pavement is shown in figure 17, plotted with respect to section length. The pavement at this time was nearly 2 years old. It will be noted that in this graph different symbols are used to distinguish between sections reinforced with the different types of steel. A study of this figure indicates that:

1. The pavement as a whole is smooth (with this apparatus, index values of the order of 80 to 120 represent smooth surfaces, 200 and above indicate rough surfaces).

2. The different types and weights of reinforcement have had no noticeable influence on the relative roughness of the various sections.

3. With modern methods of construction and proper care, the number or spacing of joints in a concrete pavement apparently need not affect its surface roughness.

The roughness index for the four special sections with weakened-plane joints at 10-foot intervals is shown on the graph as a section length of 500 feet (the distance between expansion joints). Two points are shown, one for the two sections with submerged joints and one for the two with surface joints. These sections appear to be no rougher than sections of equal length having no intermediate joints. In fact, their surface roughness appears to be about the average for the experimental pavement as a whole.

It should be pointed out that any effect of the design of the various sections on their smoothness will probably become more evident as time passes. The data presented in figure 17 are intended to furnish a basis for future comparisons.

## SUMMARY

In the course of this progress report the data that have been obtained in the several detailed surveys made during the 2 years of service life of the experimental pavement have been presented and discussed and certain trends have been pointed out.

It has been shown that in the long, heavily reinforced sections many fine transverse cracks have developed in the central area. Frequently, these cracks are no more than 2 feet apart. At all times and in all cases the cracks have remained tightly closed and no spalling, raveling, or disintegration has yet appeared at any of them.

In the sections of intermediate length containing the ½-inch diameter bars a moderate amount of transverse cracking has developed in the longer sections, and but relatively little has developed in the shorter sections.

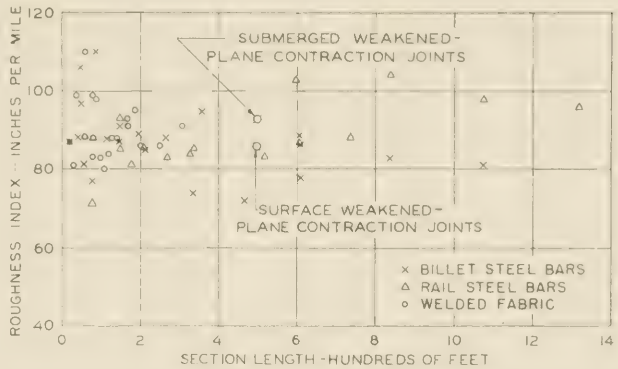



Figure 17.—Relative Roughness of Various Sections of Pavement.

In this group of sections the cracks are open slightly more than those in the sections containing the ¾-inch and 1-inch diameter bars, but there is as yet no sign of spalling, raveling, disintegration, or of inelastic deformation of the steel.

Only a limited amount of transverse cracking has occurred in the sections containing the welded wire fabric. The cracks that are present are open slightly more than those in the more heavily reinforced sections but here also no evidence of spalling, raveling, disintegration, or structural weakness has been found.

There appears to be a relationship between the length of the section as constructed and the average slab length (or distance between transverse cracks). So far there appears to be no relation between the average slab length and either the type or the amount of longitudinal steel.

The amount of change in elevation observed from season to season has been small (less than 1 inch) and has not been uniform. There is nothing to indicate that it has affected the structural integrity of the various sections.

In the four special 500-foot sections containing 10-foot slabs separated by plane-of-weakness joints, the sections as a whole are in excellent condition. The joints in which the surface groove was used are apparently perfect; those formed by a submerged parting strip have opened and raveled slightly.

Relative roughness determinations over the experimental pavement show that the surfaces of the sections were very smooth after about 18 months of service. The sections containing planes of weakness at 10-foot intervals were as smooth as those in which the joints were 1,000 feet or more apart.

(*Continued from p. 62*)

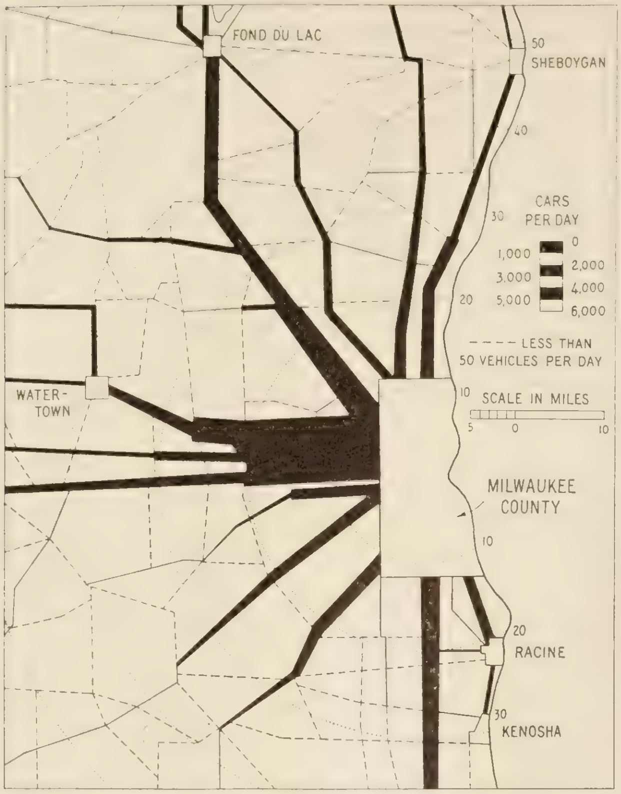



FIGURE 4.—AVERAGE DAILY TRAFFIC ON WISCONSIN STATE TRUNK HIGHWAYS IN THE VICINITY OF MILWAUKEE BY PASSENGER CARS OWNED BY RESIDENTS OF THAT CITY.

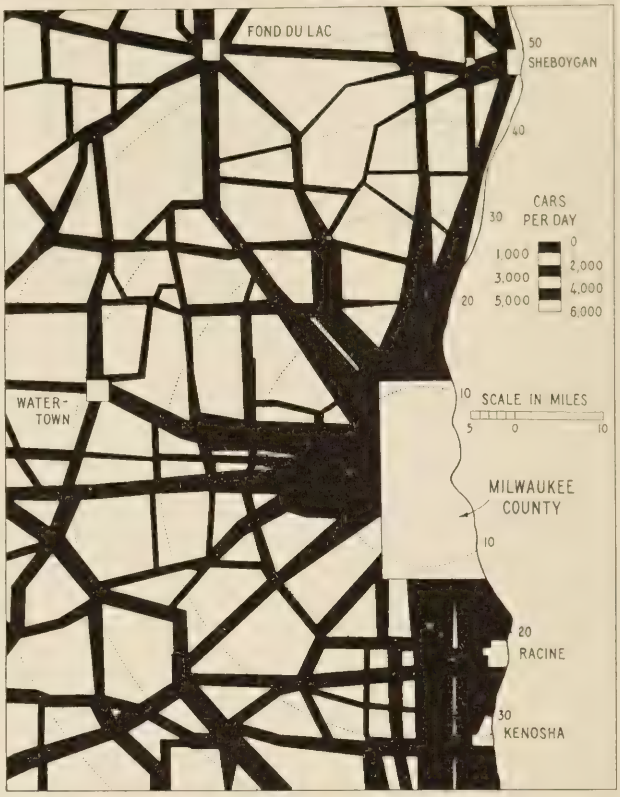



FIGURE 5.—AVERAGE DAILY PASSENGER-CAR TRAFFIC ON WISCONSIN STATE TRUNK HIGHWAYS IN THE VICINITY OF MILWAUKEE.

indicates the importance of the travel of Milwaukee residents in relation to the total travel upon the State system. The assembly of similar origin-and-destination data for all travel on the primary system on a State-wide basis would be valuable in highway administration. A study of this type would not, however, replace the special origin-and-destination studies which are necessary whenever a construction program is under consideration.

A State-wide survey made by road-use survey procedures should be looked upon as an adjunct to the special origin-and-destination study. This method would provide a qualitative approach to the problem and, if it were found desirable to obtain quantitative data, a special study could be made. The chief advantage of the State-wide method is in its comparative economy, for it is doubtful if so large a volume of useful data on travel habits could be assembled as economically in any other way. The development and use on a State-wide basis of such methods should result in a more efficient expenditure of funds for special studies since they could be planned and operated more efficiently if fairly accurate preliminary data were readily available.

# STATUS OF FEDERAL-AID HIGHWAY PROJECTS

## AS OF APRIL 30, 1941

| STATE | COMPLETED DURING CURRENT FISCAL YEAR | | | UNDER CONSTRUCTION | | | APPROVED FOR CONSTRUCTION | | | BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS |
|---|---|---|---|---|---|---|---|---|---|---|
| | Estimated Total Cost | Federal Aid | Miles | Estimated Total Cost | Federal Aid | Miles | Estimated Total Cost | Federal Aid | Miles | |
| Alabama | $ 4,103,569 | $ 1,939,044 | 101.8 | $ 5,467,643 | $ 2,721,955 | 198.4 | $ 2,281,660 | $ 1,131,100 | 76.5 | $ 2,537,658 |
| Arizona | 1,266,146 | 880,844 | 53.6 | 2,016,544 | 1,341,439 | 86.6 | 375,679 | 249,349 | 8.2 | 1,608,838 |
| Arkansas | 5,130,207 | 2,347,985 | 130.2 | 1,360,465 | 678,588 | 53.6 | 464,290 | 231,807 | 31.9 | 1,496,610 |
| California | 7,166,538 | 3,603,909 | 133.6 | 8,163,882 | 4,379,995 | 125.0 | 1,965,747 | 1,026,876 | 29.6 | 3,757,957 |
| Colorado | 2,241,641 | 1,209,449 | 189.1 | 2,640,143 | 1,529,636 | 115.1 | 694,436 | 387,979 | 69.1 | 2,992,414 |
| Connecticut | 1,936,006 | 938,685 | 16.2 | 1,585,521 | 770,582 | 16.9 | 454,236 | 223,220 | 7.0 | 1,252,523 |
| Delaware | 1,927,922 | 963,182 | 30.5 | 276,173 | 137,936 | 2.1 | 658,560 | 296,100 | 24.3 | 1,207,996 |
| Florida | 2,851,020 | 1,417,163 | 67.9 | 1,678,863 | 860,220 | 67.2 | 600,927 | 300,463 | 12.9 | 3,587,269 |
| Georgia | 3,413,741 | 1,652,691 | 199.5 | 6,959,190 | 3,489,845 | 277.9 | 1,742,340 | 871,170 | 84.0 | 6,859,825 |
| Idaho | 1,558,471 | 918,204 | 151.0 | 1,441,228 | 888,118 | 64.7 | 313,789 | 187,620 | 11.4 | 2,171,468 |
| Illinois | 6,613,731 | 3,229,261 | 152.0 | 7,897,176 | 3,949,173 | 163.7 | 3,004,000 | 1,502,000 | 63.1 | 4,648,827 |
| Indiana | 5,428,900 | 2,655,476 | 124.8 | 7,748,568 | 3,768,143 | 120.3 | 1,642,464 | 627,428 | 27.3 | 2,217,941 |
| Iowa | 5,643,387 | 2,660,020 | 198.2 | 4,435,973 | 1,944,641 | 145.6 | 1,620,134 | 773,850 | 91.2 | 1,933,064 |
| Kansas | 5,089,827 | 2,470,023 | 457.9 | 5,370,842 | 2,727,088 | 268.0 | 2,388,402 | 1,182,168 | 143.6 | 4,952,806 |
| Kentucky | 3,068,125 | 1,524,477 | 91.1 | 3,659,951 | 1,840,655 | 112.4 | 3,478,566 | 1,609,840 | 96.2 | 2,710,183 |
| Louisiana | 11,220,869 | 2,653,883 | 21.5 | 2,840,049 | 1,420,003 | 65.6 | 1,462,134 | 722,646 | 45.9 | 3,872,361 |
| Maine | 1,298,981 | 633,369 | 29.2 | 1,599,027 | 821,653 | 21.0 | 26,700 | 11,100 | .6 | 1,044,618 |
| Maryland | 1,270,568 | 623,817 | 29.1 | 3,671,262 | 1,834,513 | 29.9 | 30,000 | 15,000 | | 1,874,340 |
| Massachusetts | 1,835,469 | 914,827 | 22.9 | 2,237,791 | 1,140,056 | 13.1 | 2,101,000 | 1,049,310 | 18.8 | 3,256,329 |
| Michigan | 6,148,061 | 2,834,997 | 215.0 | 9,089,320 | 4,532,060 | 218.0 | 1,190,000 | 595,000 | 14.2 | 2,435,438 |
| Minnesota | 5,986,527 | 2,890,482 | 459.2 | 4,876,986 | 2,428,672 | 278.4 | 3,716,277 | 1,856,842 | 205.0 | 3,837,518 |
| Mississippi | 3,185,667 | 1,389,993 | 134.7 | 7,440,174 | 3,499,597 | 411.8 | 1,402,808 | 678,654 | 89.7 | 1,808,366 |
| Missouri | 3,489,129 | 1,724,918 | 172.4 | 10,305,349 | 4,769,948 | 254.0 | 5,854,280 | 2,168,349 | 161.9 | 3,943,064 |
| Montana | 4,123,613 | 2,334,341 | 283.4 | 3,298,550 | 1,863,176 | 172.7 | 466,981 | 254,505 | 16.5 | 4,439,774 |
| Nebraska | 4,724,995 | 2,215,968 | 551.5 | 4,438,469 | 2,239,272 | 470.7 | 2,910,575 | 1,455,287 | 304.7 | 2,963,205 |
| Nevada | 1,561,286 | 1,322,070 | 76.6 | 1,469,765 | 1,279,599 | 73.2 | 666,810 | 524,456 | 23.4 | 1,144,456 |
| New Hampshire | 1,420,775 | 698,400 | 36.4 | 416,295 | 206,110 | 9.0 | 682,767 | 338,757 | 9.1 | 1,086,039 |
| New Jersey | 2,277,954 | 1,117,617 | 11.8 | 6,832,152 | 3,415,996 | 52.2 | 8,930 | 4,465 | | 1,750,582 |
| New Mexico | 2,770,691 | 1,704,134 | 207.6 | 1,288,486 | 786,870 | 59.6 | 117,614 | 76,049 | 17.8 | 2,172,283 |
| New York | 11,454,784 | 5,529,723 | 199.0 | 11,652,445 | 5,797,487 | 147.1 | 379,305 | 158,800 | 5.9 | 5,006,110 |
| North Carolina | 4,356,736 | 2,175,743 | 233.1 | 5,427,752 | 2,699,750 | 231.6 | 752,782 | 364,345 | 26.6 | 2,948,948 |
| North Dakota | 1,838,668 | 977,429 | 191.9 | 2,909,164 | 1,667,024 | 242.1 | 2,711,860 | 1,373,768 | 213.0 | 4,398,366 |
| Ohio | 7,194,741 | 3,596,155 | 93.1 | 13,162,955 | 6,554,256 | 108.7 | 6,406,928 | 3,058,150 | 47.7 | 3,832,067 |
| Oklahoma | 3,168,398 | 1,675,105 | 141.9 | 2,834,704 | 1,459,696 | 87.7 | 2,460,560 | 1,265,812 | 107.2 | 4,987,628 |
| Oregon | 3,359,560 | 2,007,681 | 157.6 | 2,968,880 | 1,616,886 | 86.5 | 1,502,916 | 816,910 | 34.4 | 1,253,892 |
| Pennsylvania | 6,217,994 | 3,061,207 | 80.7 | 13,414,867 | 6,657,939 | 110.2 | 4,016,861 | 1,881,393 | 41.6 | 3,800,676 |
| Rhode Island | 1,313,964 | 642,140 | 13.3 | 928,546 | 463,642 | 7.9 | 224,982 | 112,485 | 2.6 | 1,148,877 |
| South Carolina | 2,124,454 | 1,025,792 | 162.5 | 3,612,057 | 1,700,065 | 143.5 | 1,269,792 | 352,008 | 42.9 | 2,341,294 |
| South Dakota | 3,110,156 | 1,757,293 | 530.3 | 4,099,013 | 2,560,373 | 504.8 | 1,378,170 | 807,120 | 210.8 | 3,115,069 |
| Tennessee | 2,904,745 | 1,437,397 | 65.7 | 3,960,674 | 1,980,337 | 138.8 | 2,747,316 | 1,373,441 | 34.6 | 3,909,075 |
| Texas | 8,505,414 | 4,116,472 | 494.3 | 13,671,982 | 6,761,799 | 582.6 | 3,032,920 | 1,377,895 | 164.8 | 7,556,305 |
| Utah | 995,824 | 707,521 | 73.1 | 1,203,655 | 892,909 | 47.9 | 766,825 | 442,801 | 13.0 | 1,320,975 |
| Vermont | 1,181,139 | 560,724 | 36.6 | 1,219,127 | 615,702 | 32.7 | 49,101 | 24,550 | .8 | 569,561 |
| Virginia | 2,947,748 | 1,387,772 | 73.9 | 3,997,368 | 1,884,260 | 73.1 | 893,501 | 391,495 | 13.7 | 2,421,500 |
| Washington | 4,338,626 | 2,229,972 | 91.3 | 2,019,928 | 1,078,949 | 23.3 | 522,818 | 276,815 | 4.6 | 1,645,391 |
| West Virginia | 2,205,010 | 1,095,169 | 76.4 | 4,072,160 | 2,029,598 | 79.8 | 202,850 | 101,358 | 1.4 | 1,891,416 |
| Wisconsin | 5,192,364 | 2,549,927 | 182.5 | 2,674,043 | 1,325,338 | 98.8 | 1,573,625 | 746,330 | 54.5 | 4,778,472 |
| Wyoming | 1,802,292 | 1,106,448 | 196.2 | 1,579,199 | 1,029,406 | 161.7 | 521,848 | 312,290 | 39.3 | 1,252,671 |
| District of Columbia | 498,667 | 249,021 | 5.1 | 828,211 | 413,509 | 2.6 | 281,531 | 135,481 | 1.1 | 420,250 |
| Hawaii | 236,412 | 115,318 | 4.1 | 590,134 | 314,078 | 7.8 | 138,944 | 69,472 | 2.5 | 1,954,355 |
| Puerto Rico | 519,644 | 257,240 | 10.9 | 1,567,632 | 773,930 | 22.7 | 217,350 | 107,320 | 2.1 | 931,649 |
| TOTALS | 184,221,156 | 89,730,478 | 7,462.2 | 218,900,333 | 111,542,472 | 6,888.6 | 74,374,891 | 35,901,429 | 2,749.0 | 141,048,899 |

# STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

## AS OF APRIL 30, 1941

| STATE | COMPLETED DURING CURRENT FISCAL YEAR | | | UNDER CONSTRUCTION | | | APPROVED FOR CONSTRUCTION | | | BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS |
|---|---|---|---|---|---|---|---|---|---|---|
| | Estimated Total Cost | Federal Aid | Miles | Estimated Total Cost | Federal Aid | Miles | Estimated Total Cost | Federal Aid | Miles | |
| Alabama | $ 190,944 | $ 95,263 | 9.3 | $ 1,333,057 | $ 667,758 | 60.8 | | | | $ 628,354 |
| Arizona | 240,851 | 169,480 | 23.6 | 202,398 | 149,241 | 5.3 | | | | 396,754 |
| Arkansas | 416,160 | 179,101 | 14.8 | 460,066 | 229,180 | 32.8 | | | | 309,298 |
| California | 953,657 | 512,724 | 38.2 | 1,049,656 | 750,475 | 13.4 | $ 595,573 | $ 315,639 | 14.9 | 550,009 |
| Colorado | 276,356 | 154,558 | 9.8 | 179,854 | 100,942 | 26.7 | | | | 342,799 |
| Connecticut | 370,531 | 179,413 | 4.6 | 298,035 | 136,331 | 6.1 | | | | 187,829 |
| Delaware | 127,253 | 55,914 | 12.7 | 46,219 | 22,675 | 2.9 | 258,290 | 118,835 | 12.3 | 232,397 |
| Florida | 63,276 | 31,230 | 1.6 | 1,039,527 | 519,314 | 18.7 | 85,045 | 42,523 | .2 | 285,907 |
| Georgia | 260,943 | 129,353 | 24.4 | 948,290 | 512,895 | 70.4 | 346,524 | 173,262 | 34.2 | 1,187,165 |
| Idaho | 154,346 | 91,644 | 24.0 | 300,535 | 141,337 | 13.8 | | | | 289,389 |
| Illinois | 1,746,582 | 821,040 | 80.6 | 1,158,850 | 564,425 | 46.3 | 610,290 | 284,050 | 35.1 | 556,282 |
| Indiana | 470,654 | 223,984 | 31.0 | 286,764 | 148,839 | 15.9 | 801,010 | 400,435 | 37.4 | 884,199 |
| Iowa | 2,403,069 | 1,141,236 | 524.6 | 678,813 | 317,385 | 194.0 | 60,708 | 28,850 | 23.1 | 499,687 |
| Kansas | 395,077 | 196,627 | 50.2 | 846,651 | 430,896 | 45.6 | 665,965 | 334,483 | 74.9 | 1,319,560 |
| Kentucky | 799,718 | 268,935 | 65.5 | 762,283 | 214,927 | 26.7 | 491,720 | 137,761 | 38.0 | 444,637 |
| Louisiana | 105,321 | 52,661 | 10.9 | 192,608 | 96,249 | 14.9 | | | | 718,901 |
| Maine | 303,854 | 139,080 | 17.0 | 40,606 | 20,303 | 1.5 | | | | 161,212 |
| Maryland | 128,300 | 64,150 | 5.5 | 242,390 | 121,195 | 10.6 | 213,000 | 96,000 | 8.9 | 381,665 |
| Massachusetts | 456,347 | 225,862 | 10.3 | 244,546 | 138,203 | 3.6 | 139,610 | 69,185 | 4.4 | 609,968 |
| Michigan | 1,582,553 | 742,776 | 128.6 | 732,660 | 366,330 | 27.9 | 411,300 | 205,650 | 44.4 | 686,625 |
| Minnesota | 799,202 | 387,394 | 122.5 | 946,992 | 473,496 | 114.9 | 598,120 | 267,049 | 72.5 | 945,695 |
| Mississippi | 270,229 | 133,851 | 12.5 | 789,152 | 395,926 | 42.1 | 353,700 | 165,315 | 19.2 | 651,872 |
| Missouri | 763,578 | 377,428 | 103.9 | 139,850 | 68,817 | 11.9 | 649,898 | 270,071 | 62.6 | 966,184 |
| Montana | 641,506 | 362,577 | 80.3 | 369,820 | 209,264 | 46.1 | 303,929 | 150,908 | 49.5 | 688,794 |
| Nebraska | 747,748 | 354,714 | 119.3 | 402,486 | 206,521 | 47.9 | 305,015 | 152,156 | 34.3 | 428,320 |
| Nevada | 202,910 | 164,689 | 40.9 | 178,899 | 155,725 | 14.3 | 108,993 | 94,713 | 9.7 | 142,425 |
| New Hampshire | 143,639 | 68,883 | 3.4 | 71,533 | 34,946 | 3.6 | 85,410 | 42,457 | 1.1 | 180,822 |
| New Jersey | 386,996 | 191,060 | 15.3 | 336,342 | 187,185 | 7.4 | 340,610 | 170,305 | 6.1 | 496,989 |
| New Mexico | 439,327 | 222,320 | 25.8 | 386,059 | 229,667 | 19.7 | 16,312 | 10,074 | 2.2 | 316,144 |
| New York | 2,022,102 | 951,565 | 67.9 | 1,571,934 | 788,441 | 40.5 | | | | 817,940 |
| North Carolina | 1,001,434 | 498,422 | 89.4 | 370,113 | 187,668 | 35.4 | 281,884 | 123,225 | 22.6 | 487,649 |
| North Dakota | 80,071 | 42,652 | .3 | 136,016 | 74,496 | 3.5 | | | | 1,276,906 |
| Ohio | 1,710,388 | 848,861 | 59.9 | 1,872,630 | 983,510 | 53.7 | 283,920 | 141,960 | 12.5 | 1,131,333 |
| Oklahoma | 795,576 | 416,089 | 57.1 | 301,276 | 159,134 | 14.8 | 385,480 | 203,548 | 38.4 | 1,021,808 |
| Oregon | 371,724 | 205,456 | 56.4 | 348,981 | 172,086 | 26.6 | 257,504 | 126,050 | 21.8 | 327,926 |
| Pennsylvania | 1,728,851 | 846,811 | 59.8 | 747,296 | 373,648 | 13.4 | 1,626,098 | 782,319 | 34.2 | 167,279 |
| Rhode Island | 262,488 | 120,687 | 3.6 | 93,806 | 50,516 | .9 | 142,588 | 71,080 | 1.6 | 53,344 |
| South Carolina | 635,993 | 238,916 | 90.4 | 422,540 | 139,540 | 26.1 | 606,517 | 248,108 | 35.9 | 168,691 |
| South Dakota | 3,714 | 3,624 | | 25,302 | 15,768 | 9.0 | 9,240 | 5,190 | 6.2 | 1,537,944 |
| Tennessee | 150,805 | 71,863 | 8.7 | 287,466 | 143,733 | 10.0 | 779,488 | 389,744 | 25.4 | 846,273 |
| Texas | 1,471,227 | 720,149 | 198.4 | 1,139,186 | 564,340 | 103.1 | 276,630 | 125,480 | 39.1 | 1,535,654 |
| Utah | 154,224 | 91,100 | 18.3 | 272,630 | 163,121 | 22.9 | 62,304 | 31,611 | 2.5 | 209,119 |
| Vermont | 334,397 | 116,366 | 13.5 | 193,984 | 56,234 | 7.6 | | | | 89,704 |
| Virginia | 498,464 | 236,677 | 25.2 | 438,068 | 200,991 | 19.4 | | | | 516,836 |
| Washington | 631,616 | 320,705 | 31.0 | 350,274 | 218,628 | 25.6 | 156,583 | 70,600 | 2.4 | 261,448 |
| West Virginia | 335,788 | 166,996 | 18.5 | 90,300 | 45,150 | 2.4 | 233,650 | 116,825 | 7.8 | 506,470 |
| Wisconsin | 328,957 | 163,259 | 7.4 | 868,937 | 441,443 | 28.0 | 585,173 | 253,672 | 27.6 | 684,741 |
| Wyoming | 432,361 | 260,037 | 42.8 | 369,790 | 159,928 | 18.8 | | | | 218,112 |
| District of Columbia | 112,164 | 56,082 | 1.4 | 2,192 | 1,096 | | 62,564 | 24,737 | .6 | 91,208 |
| Hawaii | 264,732 | 132,578 | 8.6 | 1,096 | 1,096 | | | | | 250,559 |
| Puerto Rico | 143,800 | 70,400 | 6.4 | 213,613 | 104,380 | 9.7 | 76,932 | 37,455 | 3.1 | 129,952 |
| TOTALS | 29,311,803 | 14,317,242 | 2,476.1 | 24,782,371 | 12,655,394 | 1,417.2 | 13,267,577 | 6,281,325 | 866.7 | 27,820,778 |

U. S. GOVERNMENT PRINTING OFFICE: 1941

# PUBLICATIONS of the PUBLIC ROADS ADMINISTRATION

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Agency and as the Agency does not sell publications, please send no remittance to the Federal Works Agency.

## *ANNUAL REPORTS*

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1933. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1934. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1935. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1936. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1937. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1938. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1939. 10 cents.

## *HOUSE DOCUMENT NO. 462*

Part 1 . . . Nonuniformity of State Motor-Vehicle Traffic Laws. 15 cents.

Part 2 . . . Skilled Investigation at the Scene of the Accident Needed to Develop Causes. 10 cents.

Part 3 . . . Inadequacy of State Motor-Vehicle Accident Reporting. 10 cents.

Part 4 . . . Official Inspection of Vehicles. 10 cents.

Part 5 . . . Case Histories of Fatal Highway Accidents. 10 cents.

Part 6 . . . The Accident-Prone Driver. 10 cents.

## *MISCELLANEOUS PUBLICATIONS*

No. 76MP . . The Results of Physical Tests of Road-Building Rock. 25 cents.

No. 191MP. . Roadside Improvement. 10 cents.

No. 272MP. . Construction of Private Driveways. 10 cents.

No. 279MP. . Bibliography on Highway Lighting. 5 cents.

Highway Accidents. 10 cents.

The Taxation of Motor Vehicles in 1932. 35 cents.

Guides to Traffic Safety. 10 cents.

An Economic and Statistical Analysis of Highway-Construction Expenditures. 15 cents.

Highway Bond Calculations. 10 cents.

Transition Curves for Highways. 60 cents.

Highways of History. 25 cents.

## *DEPARTMENT BULLETINS*

No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922. 15 cents.

No. 1486D . . Highway Bridge Location. 15 cents.

## *TECHNICAL BULLETINS*

No. 55T . . . Highway Bridge Surveys. 20 cents.

No. 265T. . . Electrical Equipment on Movable Bridges. 35 cents.

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Single copies of the following publications may be obtained from the Public Roads Administration upon request. They cannot be purchased from the Superintendent of Documents.

## *MISCELLANEOUS PUBLICATIONS*

No. 296MP. . Bibliography on Highway Safety.

House Document No. 272 . . . Toll Roads and Free Roads.

Indexes to PUBLIC ROADS, volumes 6–8 and 10–20, inclusive.

## *SEPARATE REPRINT FROM THE YEARBOOK*

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

## *TRANSPORTATION SURVEY REPORTS*

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

## *UNIFORM VEHICLE CODE*

Act I.—Uniform Motor Vehicle Administration, Registration, Certificate of Title, and Antitheft Act.

Act II.—Uniform Motor Vehicle Operators' and Chauffeurs' License Act.

Act III.—Uniform Motor Vehicle Civil Liability Act.

Act IV.—Uniform Motor Vehicle Safety Responsibility Act.

Act V.—Uniform Act Regulating Traffic on Highways.

Model Traffic Ordinances.

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A complete list of the publications of the Public Roads Administration, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to Public Roads Administration, Willard Bldg., Washington, D. C.

# STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

## AS OF APRIL 30, 1941

| STATE | COMPLETED DURING CURRENT FISCAL YEAR | | | | | UNDER CONSTRUCTION | | | | | APPROVED FOR CONSTRUCTION | | | | | BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | NUMBER | | | | | NUMBER | | | | | NUMBER | | | |
| | Estimated Total Cost | Federal Aid | Grade Crossings Eliminated by Separation or Relocation | Grade Crossing Structures Reconstructed | Grade Crossings Protected by Signals or Otherwise | Estimated Total Cost | Federal Aid | Grade Crossings Eliminated by Separation or Relocation | Grade Crossing Structures Reconstructed | Grade Crossings Protected by Signals or Otherwise | Estimated Total Cost | Federal Aid | Grade Crossings Eliminated by Separation or Relocation | Grade Crossing Structures Reconstructed | Grade Crossings Protected by Signals or Otherwise | |
| Alabama | $ 282,122 | $ 282,039 | 4 | | 5 | $ 652,503 | $ 632,450 | 5 | 1 | 3 | $ 95,990 | $ 95,990 | 2 | | 7 | $ 1,066,905 |
| Arizona | 203,065 | 195,699 | 3 | | 2 | 339,710 | 339,362 | 2 | | | 29,350 | 29,350 | | 1 | 2 | 206,818 |
| Arkansas | 701,648 | 699,956 | 7 | 1 | 14 | 951,048 | 947,106 | 9 | | 1 | 147,844 | 147,789 | 1 | | 2 | 349,302 |
| California | 461,045 | 458,655 | 4 | | 11 | 1,019,517 | 838,918 | 7 | 1 | | 700,711 | 700,711 | 2 | | 15 | 1,467,134 |
| Colorado | 7,698 | 7,698 | | | 3 | 414,112 | 414,112 | 2 | | | 374,981 | 374,981 | 3 | | 1 | 665,832 |
| Connecticut | 622,002 | 611,366 | 5 | 1 | | 166,222 | 165,415 | 2 | | | 55,869 | 54,784 | | 1 | | 563,322 |
| Delaware | 108,682 | 108,682 | 4 | | 17 | 94,135 | 94,135 | 1 | | | 4,380 | 4,380 | | | 1 | 555,841 |
| Florida | 221,540 | 217,042 | 2 | | 4 | 225,190 | 223,676 | 3 | 1 | 1 | 293,834 | 293,834 | 1 | | 27 | 1,222,179 |
| Georgia | 257,207 | 255,447 | 5 | 2 | 13 | 1,242,104 | 1,242,104 | 10 | 7 | 2 | 94,197 | 94,197 | | 1 | 6 | 2,093,193 |
| Idaho | 286,450 | 283,021 | 5 | | 32 | 17,981 | 17,981 | | | 1 | 111,151 | 111,151 | 1 | | 4 | 470,937 |
| Illinois | 1,800,577 | 1,723,632 | 10 | | 76 | 1,503,859 | 1,283,089 | 5 | 1 | 72 | 435,533 | 413,507 | 3 | | 37 | 2,415,442 |
| Indiana | 710,535 | 702,420 | 3 | 2 | 83 | 1,006,391 | 979,591 | 8 | 1 | 10 | 78,205 | 60,009 | | | 24 | 994,278 |
| Iowa | 524,629 | 498,666 | 4 | | 96 | 461,844 | 448,810 | 6 | 2 | 3 | 551,382 | 549,640 | 3 | | 30 | 852,840 |
| Kansas | 771,850 | 765,622 | 10 | | 18 | 617,231 | 617,231 | 10 | 2 | 2 | 98,301 | 98,301 | 3 | | 6 | 1,276,947 |
| Kentucky | 575,873 | 574,001 | 8 | | 11 | 982,133 | 982,133 | 9 | | 1 | 271,942 | 226,103 | 4 | | 1 | 379,372 |
| Louisiana | 100,158 | 100,158 | 1 | | | 535,658 | 482,163 | 6 | | | 604,443 | 546,718 | 5 | | 3 | 965,731 |
| Maine | 159,988 | 159,070 | 1 | 1 | 6 | 132,646 | 132,646 | 1 | 1 | | | | | | | 393,580 |
| Maryland | 183,547 | 183,543 | 1 | | 3 | 482,459 | 450,666 | 2 | 2 | 6 | 60,550 | 60,550 | | | 12 | 920,364 |
| Massachusetts | 16,588 | 16,588 | | 1 | | 426,750 | 416,111 | 2 | | | 112,050 | 111,130 | 1 | | | 2,213,796 |
| Michigan | 1,170,876 | 1,116,186 | 8 | 1 | 39 | 1,440,835 | 1,440,835 | 2 | 5 | 1 | 422,650 | 422,650 | 2 | | 4 | 862,164 |
| Minnesota | 1,447,977 | 1,436,701 | 12 | 2 | 20 | 1,057,558 | 1,057,558 | 8 | 5 | | 219,210 | 219,210 | | 2 | 2 | 1,052,684 |
| Mississippi | 263,360 | 263,360 | 3 | 1 | 1 | 674,834 | 674,834 | 9 | | | 74,999 | 74,999 | 1 | 1 | 9 | 747,725 |
| Missouri | 1,206,786 | 1,206,785 | 6 | 4 | 1 | 1,890,768 | 1,389,321 | 5 | 3 | | 156,492 | 126,400 | 1 | | | 1,363,177 |
| Montana | 434,356 | 434,356 | 5 | | 4 | 88,047 | 88,046 | 1 | | | 103,112 | 103,112 | 1 | | 3 | 508,581 |
| Nebraska | 435,090 | 432,596 | 3 | 1 | 13 | 896,294 | 896,294 | 15 | 1 | 2 | 83,378 | 83,378 | 1 | | 20 | 479,243 |
| Nevada | 72,617 | 72,617 | 1 | | 20 | 70,501 | 70,501 | 1 | | | 121,412 | 121,412 | 3 | | 5 | 104,964 |
| New Hampshire | 104,313 | 104,277 | 3 | | 1 | 146,134 | 145,314 | 3 | | | 2,703 | 2,703 | | | 1 | 426,747 |
| New Jersey | 278,937 | 278,937 | 2 | | 4 | 1,188,458 | 1,062,908 | 6 | 1 | | 63,056 | 63,056 | | 1 | 1 | 1,049,600 |
| New Mexico | 242,979 | 237,896 | 2 | | 6 | 183,821 | 175,247 | 3 | | | 159,441 | 159,441 | 1 | | | 498,988 |
| New York | 1,229,561 | 1,186,966 | 7 | 5 | 8 | 3,885,733 | 3,829,262 | 7 | 17 | | 208,090 | 160,000 | | 1 | | 3,399,087 |
| North Carolina | 589,190 | 589,122 | 8 | 3 | 29 | 721,274 | 721,034 | 6 | 6 | 10 | 236,886 | 236,886 | | 2 | 28 | 1,063,285 |
| North Dakota | 417,276 | 415,284 | 5 | | 22 | 468,443 | 468,443 | 5 | | 1 | | | | | | 844,173 |
| Ohio | 1,168,483 | 1,097,531 | 7 | 1 | 17 | 2,420,125 | 2,396,650 | 12 | 2 | | 1,892,307 | 1,835,170 | 7 | | 1 | 1,296,024 |
| Oklahoma | 653,264 | 650,890 | 10 | 1 | 52 | 372,241 | 368,825 | 3 | | 5 | 185,524 | 185,524 | 1 | | 38 | 2,170,164 |
| Oregon | 208,639 | 117,537 | 3 | | | 411,078 | 345,633 | 4 | | | 8,523 | 8,523 | | | 4 | 446,147 |
| Pennsylvania | 1,387,269 | 1,377,793 | 13 | 2 | | 2,381,629 | 2,377,801 | 19 | | | 1,892,765 | 1,774,865 | 6 | | | 2,472,159 |
| Rhode Island | 8,222 | 7,406 | | | | 206,703 | 206,703 | | 1 | | | | | | | 178,256 |
| South Carolina | 465,665 | 465,051 | 4 | 3 | 23 | 192,164 | 192,164 | 3 | 1 | 1 | 271,754 | 254,154 | 1 | 1 | 31 | 977,867 |
| South Dakota | 136,032 | 133,406 | 2 | 1 | 4 | 564,332 | 563,472 | 16 | | | 176,220 | 160,270 | 3 | | 1 | 945,932 |
| Tennessee | 244,480 | 231,146 | 2 | 2 | | 225,803 | 216,803 | 1 | 3 | | 684,903 | 684,903 | 4 | 1 | | 1,434,178 |
| Texas | 1,472,823 | 1,454,812 | 11 | 1 | 9 | 1,522,470 | 1,508,690 | 17 | | | 477,600 | 430,030 | 4 | | 1 | 2,138,008 |
| Utah | 116,959 | 116,748 | | | 44 | 58,673 | 57,931 | 2 | | 16 | 140,518 | 140,518 | 1 | | 37 | 236,899 |
| Vermont | 122,393 | 122,154 | | 1 | 9 | 137,064 | 137,064 | | 1 | 3 | 16,478 | 16,478 | | | 4 | 293,090 |
| Virginia | 234,842 | 232,573 | 2 | 2 | 12 | 764,850 | 764,630 | 6 | 3 | 1 | 114,632 | 80,772 | 1 | 1 | 4 | 807,771 |
| Washington | 362,767 | 357,785 | 4 | 2 | 10 | 440,794 | 440,794 | 3 | 3 | 1 | 9,250 | 9,250 | | | 3 | 455,123 |
| West Virginia | 119,730 | 119,730 | 1 | | 3 | 530,502 | 524,882 | 6 | | | 16,830 | 16,830 | | | 6 | 985,431 |
| Wisconsin | 825,078 | 809,586 | 6 | 4 | 7 | 553,004 | 523,781 | 4 | | 8 | 585,860 | 584,731 | 2 | 2 | 43 | 1,194,263 |
| Wyoming | 6,983 | 6,979 | | | 2 | 560,904 | 560,904 | 6 | | | | | | | | 299,298 |
| District of Columbia | 56,868 | 56,868 | 1 | | | 2,193 | 2,193 | | | | 284,230 | 280,270 | 4 | | | 275,206 |
| Hawaii | 8,416 | 8,141 | | | 2 | 194,767 | 194,759 | 2 | | | 210,515 | 210,000 | 2 | | | 181,412 |
| Puerto Rico | | | | | | 584,007 | 579,336 | 11 | | | | | | | | 302,169 |
| TOTALS | 23,487,435 | 22,984,524 | 208 | 45 | 756 | 36,107,496 | 34,690,311 | 276 | 71 | 151 | 12,940,051 | 12,418,660 | 75 | 15 | 424 | 48,563,628 |

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